Purpose

The purpose of this Quality Procedures Manual is twofold:

1) To document the quality procedures used to insure that the NIST Standard Reference Materials (SRMs) for Radioactivity Measurements are of the highest metrological quality, and
2) To document the principles and practices of the production processes so that others have ready access to the information necessary to carry on the production of the radioactivity SRMs.

The quality procedures and the production procedures must always be closely linked if a quality product is to be produced. But for most of the radioactivity SRM production processes, there is a wide range of values of individual properties and of production procedures that could be used to produce a high quality SRM. Hence, the exact values of properties and the exact production details of the current radioactivity SRMS are presented in appendices rather than in the body of the Quality Procedures Manual. The values of the properties and the production procedures given are examples of how the production process has been done, not of how it must be done. The objective is continuous quality improvement, not just maintenance of the existing quality. Continuous quality improvement may require changes in the values of some of the properties and in the production procedures. (Note that if there are significant changes in the values of some of the more important properties, a new SRM number is typically assigned.)

Background

NIST radioactivity SRMs represent the national basis for accurate radioactivity measurements. A number of commercial companies provide secondary radioactivity standards, both for specific and general needs. These secondary standards are linked to the NIST produced national standards through Measurement Assurance Programs (MAPs) with NIST. Generally, the radioactivity SRMs that are available from NIST are provided for one of several reasons: (a) they are not available from outside commercial suppliers, (b) commercially produced standards may not be traceable to national standards, (c) the accuracy of commercially produced standards is not adequate for a significant number of users, or (d) there are enough requests from the user community for a standard not otherwise available. Radioactivity SRMs can typically be classified into three general categories: (1) environmental and nuclear power, (2) medicine, and (3) basic and applied research using or involving radioactivity in the development of nuclear data and the examination of basic nuclear processes.

NIST issues a wide array of SRMs for radioactivity measurements. Typically there are 60 such SRMs in stock and calibrations have been performed on approximately 80 radionuclides. Expanded uncertainties of these calibrations are typically 2 percent or less. These calibrations are performed using approximately 40 radiometric and a few mass spectrometric methods. The SRMs are issued in a number of configurations, including gamma ray point sources mounted between thin plastic sheets, acidic solutions of alpha, beta, gamma, and X-ray emitting radionuclides, gases, and Natural Matrix materials. The NIST Natural Matrix radioactivity SRMs (see IRD Procedure 16) are a result of a collaboration of national and international environmental laboratories. These SRMs are distributed as ground, homogenized powders of soils, sediments, and organic materials and are characterized for as many as 20 radionuclides at environmental levels.

NIST radioactivity measurements are compared with the primary standards of other National Metrology Laboratories (NMIs) world-wide through the International Bureau of Weights and Measures (BIPM) which organizes and analyses the measurements. The results of such International Comparisons, as well as an extensive data file of NIST Calibration and Measurement Capabilities (CMCs), may be found on the BIPM website at www.bipm.org.

Definitions, Abbreviations, and Acronyms

Massic Activity: Activity divided by the total mass of the sample [1].

Stable: there is no chemical or physical change to the radioactivity SRM (other than the intrinsic radioactive decay) that changes a certified value by more than 25 percent of its stated uncertainty over the stated time period.

HP = Health Physics
IRSC = NIST Ionizing Radiation Safety Committee
MAP = Measurement Assurance Program
MSDS = Material Safety Data Sheet
OHSD = Occupational Health and Safety Division
RG = the Radioactivity Group of the IRD
SOP = Standard Operating Procedure(s)
TS = Technology Services
WERB = Washington Editorial Review Board

Scope

Appendix A1 lists the properties of 72 radioactivity SRMs that are in stock or in preparation as of January 2005. The certified massic activities of the radioactivity SRMs have a range of more than 15 orders of magnitude, from less than 10^{-3} Bq·g^{-1} to more than 10^{12} Bq·g^{-1}. The half lives have a range of more than 13 orders of magnitude, from less than 10^{-3} years (6 hours) to more than 10^{10} years. Radioactivity SRMs with short half lives are available only at certain preannounced times. The radionuclides range from hydrogen-3 (Z = 1) to curium-244 (Z = 96), and include solids, liquids, and gases.

For such a wide variety of radioactivity SRMs there is not a single procedure (or even a small number of procedures) that can be used to describe how they are made. There is, however, a sequence of steps that can be used to describe the production process of a SRM, including a radioactivity SRM, in a general way. The steps are:

1. Determine the intended use, the requirements, and the market for the SRM.
2. Select the chemical and physical properties of the SRM.
3. Select a suitable container and packaging for the SRM.
4. Select the chemical and physical properties whose values are to be certified.
5. Select a measurement model and suitable sampling and measurement methods.
6. Decide on a sequence of operations for the production process and what will be needed.
7. Have the proposed production process reviewed and approved.
8. Have the proposed safety measures reviewed and approved.
9. Obtain the necessary funding.
10. Arrange for the use of the necessary facilities, equipment, and personnel.
11. Acquire suitable materials.
12. Prepare and characterize the materials (as necessary).
13. Prepare the master solution or mixture.
14. Prepare the SRM solution or mixture (if different from the master)
15. Dispense the SRM solution or mixture into the SRM containers.
16. Seal the containers.
17. Sterilize the SRMs.
18. Prepare samples for measurement.
19. Measure the value of each selected property using a primary measurement method.
20. Confirm each measured value using one or more confirmatory measurement methods.

21. Measure the homogeneity between (and possibly within) SRM units.
22. Establish the traceability of each measured value to the SI.
23. Evaluate the uncertainty of each measured value.
24. Label and package the SRM containers.
25. Prepare the SRM Certificate and other required documentation.
26. Collect the production records and arrange appropriate preservation and storage.
27. Evaluate the production process and document suggested improvements.

Each of these steps will be discussed in greater detail in the Procedures section of this document. Within each step, the intent will generally be the same, but the exact sequence of the steps and the exact procedure by which each step is carried out may vary from SRM to SRM. Each of the most common procedures within each step will be described in detail in an appendix dedicated to that procedure. These appendices form a collection of "modular building blocks" from which the appropriate ones can be selected and combined to form the complete production procedure for any given radioactivity SRM. See Appendix A1 for the information necessary to construct the complete production procedure for each radioactivity SRM.

Safety

The production processes for the radioactivity SRMs involve working with radioactive materials, sometimes at very high levels of activity and dose rate, with various acids and other chemicals, and with potentially dangerous equipment. Safe work practices are an essential part of the production process. See step 8 in the procedures section.

Equipment

The production of the NIST radioactivity SRMs involves a large number of different machines and measuring instruments. See step 10 in the Procedures section.

Uncertainty Analysis

A measurement result is complete only when accompanied by a quantitative statement of its uncertainty. The uncertainty often determines the usefulness of the measurement result. The analysis and reporting of measurement uncertainties is an essential step in the production process. See step 23 in the Procedures section.

Records

The data in the production records should be complete enough so that anyone who is reasonably familiar with the SRM production processes can reproduce any or all of the calculations that lead to the final measurement results and uncertainties for the SRM (i.e., the Certificate values) and evaluate and reproduce the production process (e.g., for the next batch of that SRM).

See step 26 in the Procedures section.

Filing and Retention

The radioactivity SRM production records are stored in Building 245, Room C10 and Room E103. The production records are retained for as long as the SRM is available for sale to the public, plus at least an additional 10 years. See step 26 in the Procedures section.

The IRD Quality Manager shall maintain the original and all past versions of this IRD Procedure.

Copies of the current revision of this Procedure shall be placed in controlled Quality Manuals. Electronic copies of this Procedure are uncontrolled versions.

All deleted Procedures (including old revisions) shall be maintained by the IRD Quality Manager. All old revisions shall be maintained until such time as it is decided to delete the Procedure. Once the decision has been made to delete the Procedure, only the last revision shall be maintained by the IRD Quality Manager.

Procedures

Below is a sequence of steps that can be used to describe the production process of a SRM, including a radioactivity SRM, in a general way. For each step, the general considerations will be discussed, particularly with regard to quality issues. The exact sequence of the steps and the exact procedure by which each step is carried out may vary from SRM to SRM. More detailed information about the values of properties and the production procedure is presented in the Appendices.

Step 1. Determine the intended use, the requirements, and the market for the SRM.

Insuring that each NIST radioactivity SRM is of the highest metrological quality requires more than just having low uncertainty of the certified values. It also requires that the form, chemical composition, size, activity, and packaging of the SRM are such that the user can easily make correct and accurate measurements; the price of the SRM must also be acceptable to the intended customers. In order to help insure all of these things, the Radioactivity Group (RG) of the Ionizing Radiation Division (IRD) seeks the advice of a number of organizations, in addition to the requests and suggestions of individual customers.

If this SRM is a renewal (i.e., the production of a new batch of an already existing, but presently out-of-stock, SRM), then the previous sales record is also considered. If there is some question about the continued need for a particular radioactivity SRM, then previous customers for that SRM are usually consulted to obtain their comments and suggestions.

The market for the SRM should be carefully considered. The NIST Standard Reference Materials program is intended to be self-supporting, with the costs of production and operation fully recovered through income from sales. While it may not be practical to do this for each individual SRM, that is the goal. Calibration and certification are the primary costs of production for a radioactivity SRM, and they are relatively unaffected by the number of units produced. If the market for the SRM is too small, the cost of the SRM may be so high as to be unacceptable to the intended customers.

See Appendix A1 for the (primary) intended use for each radioactivity SRM.

Step 2. Select the chemical and physical properties of the SRM.

There are three basic guidelines for the selection of the chemical and physical properties of a radioactivity SRM:

1. The SRM should be stable for a period of at least ten half-lives of the primary radionuclide or for at least 20 years, whichever is less. Stable means that there is no chemical or physical change to the SRM (other than the intrinsic radioactive decay) that changes a certified value by more than 25 percent of its stated uncertainty.
2. The SRM should be as similar as is practical to the sample(s) that the customer will measure. This helps reduce or eliminate additional uncertainties due to dilution or due to corrections for different geometries, different photon absorptions, etc.
3. The SRM should be useable by as many customers as possible. For example, at the request of the U.S. Environmental Protection Agency, all new batches of solution radioactivity SRMs that are used as tracers for

environmental measurements are made with nitric acid. This is because stainless-steel planchets are widely used to make deposited sources for environmental measurements and nitric acid does not significantly attack stainless steel (but, for example, hydrochloric acid does).

See Appendix A1 for the chemical and physical properties of each radioactivity SRM.

Step 3. Select a suitable container and packaging for the SRM.

The three basic guidelines for the selection of a suitable container for a radioactivity SRM are the same as for selecting the chemical and physical properties of the SRM:

1. The SRM should be stable for a period of at least ten half-lives of the primary radionuclide or for at least 20 years, whichever is less.
2. The SRM should be as similar as is practical to the sample(s) that the customer will measure.
3. The SRM should be useable by as many customers as possible.

The containers currently in use for radioactivity SRMs have been selected according to these guidelines. See Appendix A1 for the container used for each radioactivity SRM.

As part of the production process, additional packaging is placed around the container for the radioactivity SRM. This packaging is designed to protect the SRM during handling and long-term storage. The packaging is designed to pass the performance tests for Type-A packages of radioactive material. The standard packagings currently in use for the radioactivity SRMs have proven satisfactory over decades of use.

Step 4. Select the chemical and physical properties whose values are to be certified.

There are two basic guidelines for the selection of the chemical and physical properties whose values are to be certified:

1. All of the properties that are essential to the proper use of the radioactivity SRM must have certified values. For example, some users are only able to dispense solution SRMs volumetrically using a pipette. Since the solution radioactivity SRMs have certified values of massic activity (activity per unit mass), the solution density must also have a certified value in order for the SRM to be useful. Similarly, some gamma-ray-emitting solution radioactivity SRMs are used for measurements as the unopened ampoule. Since the solution radioactivity SRMs have certified values of massic activity, the total mass of the solution in the ampoule must also have a certified value in order for the SRM to be useful
2. The expanded uncertainty of each value that is to be certified must be low enough to be satisfactory for the majority of users. On the other hand, calibration and certification are the primary costs of production for a radioactivity SRM and the cost of calibration varies approximately inversely with the expanded uncertainty. Hence it is important to know how low an expanded uncertainty is really needed by the majority of the users.

See Appendix A1 for the certified properties of each radioactivity SRM.

Step 5. Select a measurement model and suitable sampling and measurement methods.

The reported value, y, of activity or massic activity (activity per unit mass) at the reference time is not measured directly but is derived from measurements and calculations of other quantities. This can be expressed as $y = f(x_1, x_2, x_3, \ldots x_n)$, where f is a mathematical function derived from the assumed model of the measurement process. The value, x_i , used for each input quantity i has a standard uncertainty, $u(x_i)$, that generates a corresponding uncertainty in y, $u_i(y) \equiv \left|\partial y/\partial x_i\right| \cdot u(x_i)$, called a component of combined standard uncertainty of y. The combined standard uncertainty of y, $u_c(y)$, is the positive square root of the sum of the squares of the components of combined standard

uncertainty. The combined standard uncertainty is multiplied by a coverage factor of $k = 2$ to obtain U, the expanded uncertainty of y.

It is important to explicitly write out the function $y = f(x_1, x_2, x_3, \ldots x_n)$ and identify each of the parameters, x_i . By design, one then tries to select the parameters to be measured and to arrange the form of the function so that there is low (or no) correlation between the parameters to be measured and the function is linear (first order) in these parameters.

In addition, one tries to select parameters and carry out the measurement so that the measured values have a normal probability distribution. In most cases, this is straightforward. For example, instead of having individual parameters for gross sample counts, sample counting time, background counts, background counting time, sample counting efficiency, sample mass, sample decay time, and decay constant, one can write the function in terms of a single combined parameter called "massic activity at the reference time". This combined parameter is also more likely to have a normal probability distribution, even if one or more of the individual parameters do not.

Four possible types of measurement models are considered for the radioactivity SRMs.

1. LMNL = Linear, Multiplicative, Normal, Low Correlation
2. LMNH = Linear, Multiplicative, Normal, High Correlation
3. LMOL = Linear, Multiplicative, Other than Normal, Low Correlation
4. NMNL = Non-Linear, Multiplicative, Normal, Low Correlation

The first type of measurement model is the appropriate one for most of the radioactivity SRMs. Usually, only the Natural Matrix SRMs use any other type of measurement model. For the Natural Matrix SRMs one often encounters the third type of model, particularly with regard to massic activity versus sample size. This is because many geological and biological processes tend to concentrate the radioactive material on or in particulates.

When one of the more complicated types of measurement models is likely to be involved, consultation with the NIST Statistical Engineering Division is recommended, preferably before the measurements are started.

Measurements are made on one or more samples of the master solution/mixture to determine the values of the properties that are to be certified. In order for these measurements to be relevant to the SRM solution/mixture, the two solutions or mixtures must be gravimetrically related. In the IRD, only gravimetric measurements are used when dispensing or diluting the master and the SRM solutions.

It is clearly advantageous in terms of production effort (and often in terms of minimizing the measurement uncertainty as well) to have the master solution and the SRM solution be the same. This is done whenever practical.

For most gamma-ray-emitting radioactivity SRMs, the master solution and the SRM solution are the same solution. For the gamma-ray-emitting solutions, both liquids and gases, the unopened SRM ampoule is the sample for measurement. For the point sources, the sample to be measured is a NIST standard borosilicate-glass ampoule containing (5.0 ± 0.1) mL of master solution of known mass.

For alpha-particle-emitting and beta-particle-emitting radioactivity SRMs, the master solution and the SRM solution may or may not be the same solution. For the low-level environmental tracer solutions, the SRM solution is a quantitative dilution of the master solution. Careful and thorough mixing of the solutions is essential if the calibration of the master solution is to be relevant to the SRM solution. The master solution is gravimetrically dispensed to make point sources and/or liquid scintillation sources for measurement. If the master solution is to be diluted to make the SRM solution, this is usually done at the same time.

For the Natural Matrix radioactivity SRMs (see IRD Procedure 16), the master mixture and the SRM mixture are

always the same. It is not possible to make a satisfactory "quantitative dilution" using these materials. Samples from a randomly selected subset of all of the SRM units are used for measurement.

See Appendix A1 for the method of preparing the measurement samples for each radioactivity SRM.

The selection of a primary and a confirmatory measurement method depends primarily on the decay mode of the primary radionuclide and on the activity and physical form of the sample(s) to be measured. The general criteria for the selection of a measurement method are:

1. Non-destructive to the sample (if possible)
2. Ease of measurement
3. Ease of sample preparation
4. Low measurement uncertainty
5. Selectivity (if more than one radionuclide is present)
6. High detection efficiency (especially if the decay rate is low)

There are presently 16 basic methods, some with many variations, that are used for primary and/or confirmatory and/or impurity measurements of the radioactivity SRMs. See Appendix A1 for the measurement method(s) used for each radioactivity SRM.

Step 6. Decide on a sequence of operations for the production process and what will be needed.

After completing steps 1 through 5, and before going on to steps 7 through 10, steps 11 through 24 should be considered. In particular, one can now decide which of these steps are required, the sequence in which the required steps are to be carried out, and the facilities, equipment, personnel, supplies, and funding that will be needed. These items should be documented in writing in whatever form is satisfactory for the purpose, such as lists, tables, drawings, flow charts, Gantt diagrams, etc. Such documentation will be needed in steps 7 through 10. If there is more than one reasonable sequence, each suitable sequence should be documented.

The exact values of the properties and the exact production procedures used to produce a given batch of a given SRM may be chosen on the basis of convenience, on the basis of cost and/or availability of materials, equipment, or personnel, on the basis of production history, or on some other basis.

See Appendix A1 for the steps that were used in the production of each radioactivity SRM.

Step 7. Have the proposed production process reviewed and approved.

There should be a Coordinator of Radioactivity SRM Production designated by the Radioactivity Group Leader. (In the absence of a designated Coordinator of Radioactivity SRM Production, the review and approval are carried out by the Radioactivity Group Leader.) The Coordinator is responsible for coordinating all aspects of the radioactivity SRM production process, administrative and scientific. One of the duties of the Coordinator is to review and approve the proposed production process for each radioactivity SRM. Such review includes consideration of many issues, including the following, for each of the proposed production processes:

1. Potential hazards to persons and property
2. Availability of required resources (including facilities, equipment, and personnel)
3. Cost of production
4. Time to completion
5. Quality of the final product
6. Availability of funding
7. Selling price and demand for the SRM

Once a production process has been approved in step 7 and step 8, the Coordinator will normally carry out step 9, all or part of step 10, and possibly some of step 11.

Step 8. Have the proposed safety measures reviewed and approved by the NIST Occupational Health and Safety Division.

The production processes for the radioactivity SRMs involve working with radioactive materials, sometimes at very high levels of activity and dose rate, with various acids and other chemicals, and with potentially dangerous equipment. Safe work practices are an essential part of the production process.

The acquisition and use of radioactive material at NIST must be approved, in advance, by the NIST Health Physics Group, a part of the NIST Occupational Health and Safety Division (OHSD). For the radioactivity SRM production process, this is done by submitting a written Standard Operating Procedure (SOP) for approval. Once approved by the Health Physics Group and the NIST Ionizing Radiation Safety Committee (IRSC), the SOP is assigned an identification number and can be referenced in future production processes. Users are required to be trained and tested by the Health Physics Group before they are authorized to handle radioactive material, and are required to be retrained at least once every 2 years.

The NIST OHSD provides a number of Safe Work Practices Guides for working with dangerous material and dangerous equipment. Copies of the relevant Material Safety Data Sheets (MSDSs) and Good Work Practices Guides are available in each laboratory where such work is done. Additional safety reference materials may be found in the office of the IRD Safety Representative, in the office of the OHSD, in the NIST Library, and on the NIST OHSD website, www-i.nist.gov/admin/ohsd/hsinfo.htm.

In the end, however, safe work practice is an attitude of each person participating in the production process. It requires an awareness of the potential hazards involved in the work and a carefully considered plan of action that minimizes the risk to personnel and property.

Step 9. Obtain the necessary funding.

This step is normally carried out by the Coordinator of Radioactivity SRM Production together with the RG leader. Funding of a radioactivity SRM production from the SRM Working Capital Fund requires the approval of the IRD Administrative Officer, the IRD Division Chief, the Director of the Physics Laboratory, and the NIST Comptroller.

The funding mechanism used is not expected to have any effect on the quality of the SRM, unless the funding is inadequate to carry out the production process properly. This has not been the case at NIST. More information about the funding mechanisms used to develop and produce radioactivity SRMs can be found in the Appendices.

Step 10. Arrange for the use of the necessary facilities, equipment, and personnel

This step is normally carried out by, or in cooperation with, the Coordinator of Radioactivity SRM Production.

A number of suitable general purpose radiochemistry laboratories are available in the NIST Ionizing Radiation Division/Radioactivity Group (IRD/RG) for the preparation of radioactivity SRMs and samples for measurement. Each of these laboratories has suitable lighting and electrical power, a continuous supply of filtered and conditioned air, and supplies of hot and cold water, vacuum, pressurized air, and natural gas. Each laboratory has exhaust hoods designed for use with radioactive materials. The main weighing room has a humidifier in the air supply.

Environmental conditions in these laboratories that are within the range of human comfort, and that are within the range of human health and safety, have little effect on the quality of the SRMs produced. During mass

measurements, the temperature, pressure, and relative humidity of the air are measured and recorded. These data are used to compute the air buoyancy correction. Within the extreme ranges of (25 ± 10) °C, (101 ± 3) kPa, and (45 ± 30) percent relative humidity, the air buoyancy correction varies less than 0.02 %. Even if nominal values were used for the temperature, pressure, and relative humidity, rather than measured ones, the difference would not be significant. During solution density measurements, the solution temperature is measured and recorded. This data is used to compute the temperature correction to get the density at the reference temperature (usually 20 °C). Within the normal range of temperatures in these laboratories, (22 ± 3) °C, the density correction is less than 0.1 %. Even if a nominal value of 20 °C were used, rather than the measured one (i.e., no temperature correction is made), the error in the solution density would normally be less than 0.05 %.

The thermometers actually used are calibrated to within 0.2 °C, some to within 0.1 °C, by the NIST Thermometry Group. The instruments used to measure pressure are calibrated to within 1 kPa and the instruments used to measure relative humidity are calibrated to within 5 %. In any case, the uncertainty in the calibration of the instruments is such that the contribution to the uncertainty of the measured value of mass or density is negligible. None-the-less, all corrections are calculated and each uncertainty contribution is included in the calculation of the uncertainty of the mass or density measurement.

The environmental condition that has the largest effect on the mass measurements and on the radioactivity measurements is static electricity. For example, the change in apparent mass of a polyethylene pycnometer (such as might be used to dispense 50 mg of solution to a point source or to a measurement sample) can be as much as several milligrams after wiping it off (charging it up) with a Kimwipe. This corresponds to a weighing error of several percent. The effects of static electricity are most noticeable during the months of November through April, but care must always be taken to control static electricity. The electrical conductivity of the air can be increased through the use of a humidifier and/or an ionizer. Containers of glass have much higher electrical conductivity than containers of plastic, but we use plastic containers to weigh out small masses of radioactive solution because glass containers are not practical. We do not at present have adequate control of static electricity for low-mass measurements made during the months of November through April. Significant additional time is spent waiting for the static electricity to dissipate and additional uncertainty is introduced into the mass measurements.

The production of the NIST radioactivity SRMs involves a large number of different machines and measuring instruments. Most of these items are the property of the IRD/RG. In addition, there are items available for use that are the property of other divisions at NIST, such as Measurement Services Division (MSD), or that are the property of other governmental agencies (OA), or that are the property of commercial companies (COM). Equipment items that are not the property of the IRD/RG are usually associated with the processing of the Natural Matrix SRMs and are used under contract or on an exchange of services basis.

It is the intent of the IRD/RG that there be enough units of each type of equipment available so that no one piece of equipment is essential to the production process of any SRM. For example, the preparation of 50 mg radioactive point sources may require a microbalance with a capacity of >7 g, a readability of <5 μg, and a standard uncertainty of <50 μg (relative to the SI). The IRD/RG currently has at least 6 balances that meet these specifications, all of which are serviced and calibrated once per year with masses traceable to the SI. The 3 newer electronic balances have built-in calibration masses and their calibration can be checked at the beginning of each weighing sequence. Similar redundancy exists for most of the other equipment that is the property of the IRD/RG.

The most important piece of equipment for which there is not yet adequate redundancy is the 4πγ pressurized ionization chamber (PIC "A") in Building 245, Room B47. PIC "A" is used to compare the ionization current produced in the chamber by (1) a photon-emitting radionuclide dissolved in (5.0 ± 0.1) mL of solution inside a NIST standard 5 mL borosilicate-glass ampoule (or a gas in a 5 mL NIST gas ampoule) with (2) a radium-226 reference source (RRS) in a welded stainless-steel capsule that is embedded in the center of a plastic rod whose dimensions are similar to those of a NIST ampoule. The NIST ampoule and the RRS are each held at a reproducible position within

PIC "A". Under these conditions, the activity of a given radionuclide that produces the same current in PIC "A" as a given RRS is the calibration factor, called the *K-value*, for that RRS and that radionuclide.

Although the *K-value* is a property of a given RRS and a given radionuclide, it is also a property of the particular ionization chamber (or at least the type of ionization chamber) in which it is measured. This is because the gamma-ray emission spectra of the radionuclide and of the RRS are, in general, different and different ionization chambers have different gamma-ray energy response curves. The provision of redundancy for PIC "A", and also for the RRSs, is a high priority task for the RG.

Another important piece of equipment for which redundancy is needed is the 4π(LS)-gamma-anticoincidence counting system in Building 245, Room C15. Over the last 27 years this system has been used to perform direct activity calibrations for many radionuclides. These calibrations form the basis of many of the *K-values* used with the RRSs and PIC "A". The system is also used for many of the direct measurements that are done as part of the BIPM International Comparisons of Radioactivity. An upgraded version of this system will be designed and built.

More information about the various equipment can be found in the Appendices.

The personnel involved in the actual handling of the radioactivity SRM solution or mixture should have a good knowledge of analytical chemistry laboratory techniques, a good knowledge of physical chemistry instrumental techniques, and an awareness of the chemical and/or radiological hazards involved. They also need complete and accurate information about the production process that they are to carry out. That is one of the reasons for this Quality Procedures Manual and the extensive appendices.

More than anything else, though, the production of a high quality SRM depends upon the competence and the conscientiousness of the people involved. The question is how best to foster these qualities. Education is important, but studies consistently show that the workplace "atmosphere" (appreciation, support from management, fairness, reasonable workload, opportunity to do satisfying work, etc.) is the most important factor in increasing the quality of the work that people do. NIST as a whole receives high marks from its employees in most of these areas. In the case of the IRD/RG, the main criticism is that the workload for many of the people in the group is much too high. This has not affected the quality of the SRMs produced, but it has definitely affected the time to delivery and the number of radioactivity SRMs that are out of stock. No short term solution is in sight.

Step 11. Acquire suitable materials.

As used here, materials include

a. the radioactive material for the radioactivity SRM,
b. chemical reagents and other consumable materials, and
c. SRM containers, glassware, and other laboratory supplies.

Today most radionuclides (other than Special Nuclear Material) that are used to produce radioactivity SRMs are available from commercial suppliers. Radionuclidic purity and carrier concentration vary somewhat, but one can usually purchase suitable radioactive starting material that does not require any additional chemical purification. A few radionuclides that are used for radioactivity SRMs are the parent of a radioactive decay chain and chemical purification may be necessary to improve the calibration accuracy or because of the way in which the SRM is used. Special Nuclear Material is usually obtained through the U.S. Department of Energy (USDOE). It may require additional chemical purification before it is suitable for calibration and/or use.

For the Natural Matrix radioactivity SRMs (see IRD Procedure 16), the acquisition of suitable material can be more complicated. Usually as the result of a recommendation of an advisory group (see Step 1), a particular composition and massic activity are desired. It is often the case that material with the desired chemical and radionuclidic

composition is available, but its massic activity is much too high to be suitable without dilution by a large factor (as high as 100:1). In this case, suitable similar material with low massic activity must also be obtained for the dilution. For good homogeneity of the diluted mixture, the material used for dilution should have the same density and particle-size distribution as the material to be diluted. Finding materials that meet all of these requirements can be a challenge.

Chemical reagents used as solvents and non-radioactive carriers are at least Analytical Grade reagents, and each bottle is provided with a lot analysis. Spectroscopic Grade reagents or Trace Element Grade reagents are preferred.

Borosilicate glass or Teflon containers are always used for solution radioactivity SRMs.

Step 12. Prepare and characterize the materials (as necessary).

The SRM containers, glassware, and other laboratory supplies are prepared, as necessary, using standard analytical laboratory techniques for washing, rinsing, drying, labeling, etc.

Chemical reagents are usually stored in their original container in the laboratory, protected from contamination, until they are used.

For most of the radioactivity SRMs, the radioactive starting material is received as a solution. The material is measured for radiological (and sometimes chemical) impurities. This is typically done using gamma-ray spectrometry. If the radioactive material is a pure alpha-particle emitter or a pure beta-particle emitter, a portion of the solution may also be measured using alpha-particle or beta-particle spectrometry. Depending upon the nature and level of the impurities, additional chemical separation may be required.

For the Natural Matrix radioactivity SRMs (see IRD Procedure 16), the starting material is received as a solid (e.g., soil, vegetation, or animal tissue).

Step 13. Prepare the master solution or mixture.

The master solution or mixture is the material that is actually calibrated and the measurements on this material are used to determine the certified values. It is always gravimetrically related to the SRM solution or mixture. The massic activity of the master solution is optimized for the calibration measurements and is usually higher than the massic activity of the SRM solution. In some cases, the massic activity of the master solution is the same as, or lower than, the massic activity of the SRM solution. In the latter case, the SRM solution is made before the master solution. See the discussion in Step 5.

Step 14. Prepare the SRM solution or mixture (if different from the master)

For the solution radioactivity SRMs, the density of the SRM solution is measured and certified because some users are only able to dispense solution SRMs volumetrically using a pipette. In the IRD/RG, only gravimetric measurements are used when dispensing or diluting the master and the SRM solutions. See the discussion in Step 5.

Step 15. Dispense the SRM solution or mixture into the SRM containers.

For a point source, this consists of gravimetrically dispensing from as little as 15 mg, to as much as 300 mg, of the SRM solution unto the center of the point source mount (filter round on adhesive polyester tape, bare tape, or stainless-steel disk) using a small plastic pycnometer. The mass dispensed depends upon the desired activity for the point source and the type of point source mount (plastic or stainless steel). A larger dispensed mass has a lower relative uncertainty associated with the measurement of the mass, but a smaller area for the deposited radionuclide is

also desirable, especially when using the plastic source mounts. For the plastic source mounts, a deposited solution mass of 15 mg to 50 mg is usually satisfactory.

Solution radioactivity SRMs are prepared using a precision liquid dispenser to dispense the SRM solution. For gamma-ray-emitting solution SRMs, the volume of solution is (5.0 ± 0.1) mL in a NIST standard 5 mL borosilicate-glass ampoule (from a NIST ampoule stock reserved for this purpose), and each ampoule is weighed before and after filling. This is because some gamma-ray-emitting solution SRMs are used for measurements as the unopened ampoule. Since the solution radioactivity SRMs have certified values of activity per unit mass, the total mass of the solution in the ampoule must also have a certified value.

For alpha-particle-emitting and beta-particle-emitting radioactivity SRMs, the ampoules are also made of borosilicate glass but need not be NIST standard 5 mL ampoules. The volume of solution is approximately 5.0 mL and some of the ampoules (usually >10%) are weighed before and after filling. The mass of the solution may or may not be a certified value. It is not necessary because alpha-particle and beta-particle measurements cannot be made on the solution in an unopened ampoule.

For gaseous radioactivity SRMs, the borosilicate-glass gas ampoules are filled to a measured pressure, usually somewhat less than atmospheric pressure, using a vacuum rack and a gas transfer system. No attempt is made to measure the exact volume of a gas ampoule. Gas ampoules are certified in terms of the total activity in each ampoule.

For Natural Matrix radioactivity SRMs (see IRD Procedure 16), the SRM mixture is dispensed into wide-mouth bottles of appropriate size and construction.

Step 16. Seal the containers.

Point sources: After the deposited solution dries, the point source is covered and sealed using another layer of adhesive polyester tape (or using another stainless-steel disk that is then welded around the edge).

Ampoules: All ampoules are flame sealed.

Natural Matrix materials: Animal tissue is sealed in an air-tight package with the oxygen excluded, such as in a glass serum vial packed under vacuum or in a plastic bottle overpacked in heat-sealed aluminized Mylar bag, all under nitrogen. All other materials are in bottles with screw-on caps.

Step 17. Sterilize the SRMs.

Some of the solution radioactivity SRMs are sterilized in a pressure cooker for 15 minutes at 15 psi to kill any organisms that may be present. This is important for those SRM solutions that have a pH between 1 and 13. The growth of organisms in solutions with pH greater than 13 or less than 1 is unlikely. The sterilization also serves as a pressure test for the seal on the ampoule. After sterilization, the ampoules and the pressure cooker are checked to determine if there was any leakage of radioactive material.

The point source radioactivity SRMs are not sterilized (except by their own radiation).

The Natural Matrix radioactivity SRMs (see IRD Procedure 16) are sterilized using gamma-ray irradiation.

Step 18. Prepare samples for measurement.

For the gamma-ray-emitting solution radioactivity SRMs, both liquids and gases, the SRM is the sample for

measurement. For the point sources, the sample to be measured is a NIST standard borosilicate-glass ampoule containing (5.0 ± 0.1) mL of master solution of known mass.

For the alpha-particle-emitting and beta-particle-emitting radioactivity SRMs, the master solution is the sample for the calibration measurements. The master solution is gravimetrically dispensed to make point sources and/or liquid scintillation sources for measurement. In addition, some of the SRM ampoules (typically the first, middle, and last ampoule filled) are opened and similar sources are made to check the gravimetric dilution ratio between the master solution and the SRM solution. In general, the uncertainty associated with the direct measurement of the dilution ratio will be much larger than the uncertainty associated with the gravimetric measurements. The direct measurement serves as a check on any serious error in the gravimetric measurements, in the calculations, or in the thoroughness of mixing the solution.

For the Natural Matrix radioactivity SRMs (see IRD Procedure 16), the SRM is the sample for measurement. Samples from a randomly selected subset of all of the SRM units are used for measurement.

See Appendix A1 for the method of preparing the measurement samples for each radioactivity SRM.

Step 19. Measure the value of each selected property using a primary measurement method.

Once a basic calibration for a given radionuclide is developed, it is then used in the Radioactivity Calibration Service and in the production of radioactivity SRMs. The Radioactivity Calibration Service lists more radionuclides than are available as radioactivity SRMs. This is because the half life of some of the radionuclides is too short and/or the demand is too low.

The calibration of a radioactivity SRM, regardless of the particular measurement method used, is basically the same as the calibration of a comparable source from an outside customer. The differences are that the master solution for the SRMs is usually better characterized, that the activity or massic activity is optimized for the measurement method, and that more measurements are made. Hence, the measurement uncertainties are typically lower for the SRMs than for the customer sources.

For the gamma-ray-emitting solution radioactivity SRMs, both liquids and gases, each ampoule is measured in Pressurized Ionization Chamber "A" (PIC "A") to determine the total activity of the primary radionuclide. Corrections are made for the response due to any other photon-emitting radionuclides present.

For the Natural Matrix radioactivity SRMs (see IRD Procedure 16), samples of the SRM are sent to a number of environmental laboratories throughout the world. They are sent with NIST calibrated tracer solutions, which are typically diluted solution radioactivity SRMs. Each laboratory has many years of experience and can measure some, but not necessarily all, of the radionuclides of interest. The methods used also vary from laboratory to laboratory.

See Appendix A1 for the primary measurement method used for each radioactivity SRM.

Step 20. Confirm each measured value using one or more confirmatory measurement methods.

Where possible, independent confirmatory measurement methods are used to verify the results from the primary measurement method. Comparison with samples from one or more of the previous batches of the same SRM is also used when such samples are available. In some cases, such as photon spectrometry, the calibration of the photon detector is based on the same basic calibration that is used for the SRM; a situation quite common for the basic calibrations held on PIC "A". In this case, one is only confirming the consistency of the relationships to the same common calibration. One is not confirming the accuracy of the basic calibration itself.

A confirmatory method is also used to measure one or more of the individual radioactivity SRMs when the SRM solution is not the master solution. This serves as an additional check on the dispensing and/or dilution of the master solution.

See Appendix A1 for the confirmatory measurement method(s) used for each radioactivity SRM.

Step 21. Measure the homogeneity among (and possibly within) SRM units.

The homogeneity among radioactivity SRM units is usually confirmed by making measurements on several units within the same batch.

For gamma-ray-emitting solution radioactivity SRMs, the massic activity of the solution in each ampoule can be calculated from the measured activity and the measured solution mass. The massic activities are checked for deviant values and for correlations (such as with dispensing sequence or mass of solution).

For gamma-ray-emitting point sources, each point source can be measured with reproducible (but not necessarily known) efficiency. The massic response for each point source can be calculated from the measured response and the measured mass of solution dispensed unto the point source. The massic responses are checked for deviant values and for correlations (such as with dispensing sequence or mass of solution). The activity of one of more of the point sources can be determined (usually using a calibrated photon spectrometry system) and compared with the activity expected from the mass of calibrated solution dispensed unto the source.

For alpha-particle-emitting and pure beta-particle-emitting solution radioactivity SRMs, several ampoules (typically one of the first, middle, and last of the ampoules filled) are opened and the massic activity of each solution is measured. The massic activities are checked for deviant values and for correlations (such as with dispensing sequence).

For the Natural Matrix radioactivity SRMs (see IRD Procedure 16), homogeneity within each SRM is also important because typically only a part of the total mass of the unit is taken for a measurement. As part of the measurement process at the various participating laboratories, subsamples of various sizes from the same SRM unit, as well as from different units, are measured and compared to evaluate the homogeneity between and within samples. Each laboratory receives several units of the SRM, randomly selected from the total number of SRMs that were made.

See Appendix A1 for the homogeneity test(s) used for each radioactivity SRM.

Step 22. Establish the traceability of each measured value to the SI.

For the solution radioactivity SRMs, the typical certified values are:

1. Radionuclide(s),
2. Massic Activity(ies),
3. Expanded Uncertainty(ies),
4. Reference Time,
5. Solution Mass, and
6. Solution Density at a reference temperature (usually 20 °C).

For gas ampoules and point sources, the certified values are:

1. Radionuclide(s),
2. Total Activity(ies),
3. Expanded Uncertainty(ies), and

4. Reference Time.

For Natural Matrix materials, the certified values are:

1. Radionuclides,
2. Massic Activities,
3. Expanded Uncertainties, and
4. Reference Time.

The SI base units used to express these certified values are time, mass, length, and temperature. The realization of these SI base units as US National Standards is well established with very low relative uncertainty.

The measurements made as part of the calibration of a radioactivity SRM are linked through the US National Standards at NIST to the SI as follows:

1. Time
   Time increments are measured by counting the number of cycles from a Temperature Compensated Crystal Oscillator whose frequency was measured using a frequency meter traceable to the US National Standards at NIST. Measurements of clock time are made using direct time transmissions from NIST Boulder.
2. Mass
   Balances and scales used to measure the mass of the SRM solution (or solid) are serviced and calibrated at least once per year using masses (weight sets) directly traceable to the US National Standards at NIST. The newer electronic balances have built-in calibration weights, so the calibration can be checked before each set of weighings.
3. Length (Volume)
   Volumetric glassware used to determine the solution density is Class A glassware and is gravimetrically calibrated using distilled water and the well-established relationship between the density of pure water and the temperature.
4. Temperature
   Temperature measurements used in the determination of the air buoyancy correction and the solution density use thermometers calibrated to within 0.2 °C, some to within 0.1 °C, by the NIST Thermometry Group.
5. Pressure
   Instruments used to measure atmospheric pressure are calibrated to within 1 kPa (0.01 atmosphere), by the NIST Pressure and Vacuum Group.
6. Relative Humidity
   The manufacturer's stated accuracy for instruments used to measure relative humidity are sufficient.

The determination of activity requires that the number of radioactive decays that occur during a finite time interval be counted. The time interval can usually be chosen so as to make its uncertainty negligible. The difficulty lies in determining the efficiency of the detector for the radioactive decays. Every radioactivity detector has some intrinsic inefficiency, has a finite size (and hence boundaries), cannot detect radioactive decays that deposit less than some minimum amount of energy in the detector (threshold), and gives some count rate even in the absence of radioactive decays in the source (background count rate). The efficiency of a single detector (decays detected / total decays) cannot be verified without reference to one or more other detectors.

The efficiency of a detector has to be calculated on the basis of one or more theoretical measurement models, each of which has some inherent uncertainty. For radioactive decay, the theoretical measurement models with the lowest uncertainties are those that use multiple detectors, time correlation measurements, and efficiency extrapolations. (See references [4], [5], [6].) These measurement models (and the related measurement methods - coincidence and anticoincidence counting with efficiency-extrapolation techniques) cannot be used with all radionuclides or types of decay. But activity calibrations using these models and techniques have become the cornerstone of the international measurement system for radioactivity. The calibration of virtually all radioactivity measurement instruments is

based upon them.

In order to confirm the accuracy of the NIST radioactivity measurements, they are compared with the radioactivity measurements of other National Metrology Laboratories (NMIs) world-wide through the International Bureau of Weights and Measures (BIPM), which organizes and analyses the measurements. The results of such International Comparisons, as well as an extensive data file of NIST Calibration and Measurement Capabilities (CMCs), may be found on the BIPM website at www.bipm.org.

Step 23. Evaluate the uncertainty of each measured value.

Measurement uncertainty is evaluated in accordance with the *Guide to the Expression of Uncertainty in Measurement* [2] and the *Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results* [3].

In general, the uncertainty components associated with the instruments and artifacts used to measure time, mass, length (volume), temperature, pressure, and relative humidity, are small and reasonably well known. For most radioactivity SRMs, the largest component of uncertainty arises from the uncertainty in the detection efficiency for the radioactive decays. The uncertainties associated with the detection efficiency (decays detected / total decays) vary with the type of radioactive decay, with the type of detector, and with the measurement method.

Radioactive decay is also inherently a statistical (Poisson) process. The method of computing the expectation value of the mean rate and the variance for such a process is well known. For sources with very low levels of radioactivity, such as the Natural Matrix radioactivity SRMs (see IRD Procedure 16), the uncertainty due to the variance of the counting rate can be a large (or the largest) uncertainty component.

Each radioactivity SRM Certificate issued since 1994 includes a table listing all known significant sources of uncertainty. (See the example Certificates in the Appendices.) Many of the radioactivity SRM Certificates issued before 1994 also included such information, but in a less comprehensive form.

It is important to emphasize that the value of each standard uncertainty component, and hence the value of the expanded uncertainty itself, is a best estimate based upon all available information, but is only approximately known. That is to say, the "uncertainty of the uncertainty" is large and not well known. This is true for uncertainties evaluated by statistical methods (e.g., the relative standard deviation of the standard deviation of the mean for the massic response is approximately 50%) and for uncertainties evaluated by other methods (which could easily be over estimated or under estimated by substantial amounts). The unknown value of the expanded uncertainty is believed to lie in the interval $U/2$ to $2U$ (i.e., within a factor of 2 of the estimated value).

See Appendix A1 for the radionuclide, the decay mode(s), the expanded uncertainty, the measurement method(s), and other data for each radioactivity SRM.

Step 24. Label, package, and store the SRM containers.

As part of the production process, additional packaging is placed around the container for the radioactivity SRM. This packaging is designed to protect the SRM during handling and long-term storage.

In addition to having the radioactivity SRM clearly labeled for proper identification, the US Department of Transportation (USDOT) and the US Nuclear Regulatory Commission (USNRC) require that the labeling and packaging of radioactive material conform to specific regulations. The standard international radioactivity symbol and the proscribed wording must be on the container to warn the user of the radioactivity hazard.

Also proscribed is the level of activity and/or massic activity above which the radioactivity SRM is considered to be radioactive material for licensing and inventory purposes (specified in the NIST NRC license) and the level above which the radioactivity SRM is considered to be radioactive material for shipping purposes (specified in US 49 CFR 173, and in the IATA Dangerous Goods Regulations). The two levels are not the same and are occasionally revised. The Natural Matrix radioactivity SRMs (see IRD Procedure 16) are not considered to be radioactive material for shipping purposes. Additional requirements for liquid sources include absorbent material and secondary containment in case the innermost container should leak. The NIST Health Physics Group should be consulted if there is any question about the levels or the labeling, packaging, and shipping requirements.

The packaging is designed to pass the stringent performance tests specified for Type-A packages of radioactive material (except for the minimum size requirement). The standard packagings currently in use for the radioactivity SRMs have proven satisfactory over decades of use.

Step 25. Prepare the SRM Certificate and other required documentation.

In order to be useful to the user, the radioactivity SRM must be accompanied by one or more documents that provide information about the composition, the properties, and the proper use of the SRM. For radioactivity SRMs, these documents consist of the Material Safety Data Sheet (MSDS) (if required), the NIST Certificate, and the Additional Information for Users (where appropriate). For an example, see Appendix A3.

Under U.S. law, a MSDS must be provided whenever the material has a physical, chemical, or biological hazard (as defined in the law). Under U.S. law, MSDSs do not cover radiological hazards. The MSDSs for all SRMs, including radioactivity SRMs, are produced by the MSD.

The NIST Certificate for a radioactivity SRM contains:

1. The SRM number,the batch number or letter (where appropriate), and the name of the primary radionuclide.
2. General information regarding the composition and packaging, the intended use, the chemical and radiological hazards, the proper storage and handling, the expiration date, and the people involved in the preparation of the SRM.
3. The "Recommended Procedure for Opening the SRM Ampoule" (for solution radioactivity SRMs only).
4. The values and uncertainties of the properties for which the SRM is certified.
5. Uncertified values of other properties that may be of interest to the user.
6. A table of the uncertainty components for the certified value of the activity, or the massic activity, in accordance with the *Guide to the Expression of Uncertainty in Measurement* [2] and the *Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results* [3].
7. Notes and references.

The form and contents of the NIST Certificate used for all new radioactivity SRMs was reviewed and approved by the Washington Editorial Review Board (WERB) in 1994. In addition, each Certificate is approved (as a minimum) by the Coordinator of Radioactivity SRM Production, the Group Leader of the Radioactivity Group, the Division Chief of the Ionizing Radiation Division, a statistician in the Statistical Engineering Division (where appropriate), and by the Chief of the Measurement Services Division (MSD) before it is issued to the public. A signed and dated approval sheet accompanies the Certificate when it is sent to the MSD.

When the nature or use of a radioactivity SRM requires more information than can reasonably be included within the NIST Certificate itself, a separate document called "Additional Information for Users of SRM 4xxx" is also provided. This document is intended to provide additional detail about the proper use of the SRM or to explain how and why the calibration has changed from previous batches of the same SRM. Examples include how to correct for the summing of photons in close geometry for radionuclides with decay cascades, and how to properly condition and use the radium-226/radon-222 emanation standards. This document is approved (as a minimum) by the Coordinator

of Radioactivity SRM Production, the Group Leader of the Radioactivity Group, and the Division Chief of the Ionizing Radiation Division before it is issued to the public.

Step 26. Collect the production records and arrange appropriate preservation and storage.

The production of a radioactivity SRM requires a written plan outlining the details of the starting materials, the procedures and equipment to be used, the number of units to be made, etc. During the production processes additional data is recorded, such as mass, volume, temperature, humidity, clock and elapsed time, and the outputs from various radioactivity measuring devices. The data may be in the form of paper, floppy disks, and/or CD-ROMs. These data are used to calibrate the SRM and to determine the certified values. All of the information for the production of most of the radioactivity SRMs is collected and stored in one or more three-ring binders in Building 245, Room E103.

The data stored is intended to be complete enough so that anyone who is reasonably familiar with the radioactivity SRM production processes can (1) reproduce any or all of the calculations that lead to the final measurement results and uncertainties for the SRM (i.e., the Certificate values) and (2) can evaluate and, if desired, reproduce the production processes for the next batch of that SRM.

The production information is retained for as long as the SRM is available for sale to the public, plus at least and additional 10 years.

Step 27. Evaluate the production process and document suggested improvements.

In carrying out the production process, there are sometimes procedures, equipment, supplies or other situations which do not work out optimally. These deficiencies, whether large or small, should be documented in the production records and brought to the attention of the Coordinator of radioactivity SRM Production. By the same token, things that work really well should also be documented.

The intent is to improve the production process by modifying the procedures, the equipment, the supplies, or the situation, so that everything works really well. This is an evolutionary process and it works better if everyone involved in the production process gets together afterward to discuss the improvements that could be made.

References

The first four references below are of general interest. The calibration and/or production processes for some of the radioactivity SRMs have been published in the literature. Where this is the case, it is noted under "Other Information" in Appendix A1 and the reference is listed below.

[1] International Organization for Standardization (ISO), *ISO Standards Handbook - Quantities and Units*, 1993. Available from Global Engineering Documents, 12 Inverness Way East, Englewood, CO 80112, U.S.A. Telephone 1-800-854-7179.

[2] International Organization for Standardization (ISO), *Guide to the Expression of Uncertainty in Measurement*, 1993 (corrected and reprinted, 1995). Available from Global Engineering Documents, 12 Inverness Way East, Englewood, CO 80112, U.S.A. Telephone 1-800-854-7179.

[3] B.N. Taylor and C.E. Kuyatt, *Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results*, NIST Technical Note 1297, 1994. Available from the Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20407, U.S.A.

[4] National Council on Radiation Protection and Measurements Report No. 58, *A Handbook of Radioactivity Measurements Procedures*, Second Edition, 1985. Available from the National Council on Radiation Protection and Measurements, 7910 Woodmont Avenue, Bethesda, MD 20814 U.S.A.

[5] International Commission on Radiation Units and Measurements (ICRU) Report 52, *Particle Counting in Radioactivity Measurements*, 1994. Available from ICRU Publications, 7910 Woodmont Avenue, Bethesda, MD 20814 U.S.A.

[6] W.B. Mann, A. Ritz, and A. Spernol, *Radioactivity Measurements - Principles and Practice*, 1991, Pergamon Press, Oxford.

Appendix A1: Properties and Preparation of the NIST Radioactivity SRMs, as of January 2005.
Certified values are in bold type. Abbreviations and Notes are provided at the end of Appendix A1.

SRM Number	4201B	4218F	4222C	4226C
Radionuclide	**Nb-94**	**Eu-152**	**C-14**	**Ni-63**
Decay Mode(s) (>1%)	BP,GR	BP,EC,GR	BP	BP
Half Life	20.3 ka	13.537 a	5.70 ka	100.1 a
Intended Use	CAL(Ge,NaI)	CAL(Ge,NaI)	CAL(LSC)	CAL(LSC)
Physical State	Solid	Solid	Liquid	Liquid
Chemical Form	NbO	$EuCl_3$	n-Hexadecane	$NiCl_2$
Solution/Mixture Composition	-	-	n-Hexadecane	0.9 M Hcl
Solution/Mixture Mass (g)	-	-	~5	**5.080**
Solution density ($g \cdot mL^{-1}$)	-	-	**0.771**	**1.014**
Containment	PSG	PSG	5AMP	5AMP
Non-radioactive Carrier	NbO	$EuCl_3$	None	$NiCl_2$
Carrier Concentration ($mg \cdot L^{-1}$)	~140 ug total	~10 ug total	-	220
Massic Activity ($Bq \cdot g^{-1}$)	**~4 kBq total***	**<150 kBq total***	**54.02 k**	**50.53 k**
Reference Time	**Apr 1970**	**01 Jan 1999**	**03 Sep 1990**	**15 Aug 1995**
Expanded Uncertainty (k=2) (%)	**1.5**	**0.78**	**0.81**	**0.92**
Source of Starting Material(s)	PUR(COM)	PUR(USDOE)	PUR(COM)	PUR(COM)
Preparation of Starting Material(s)	None	None	None	None
Impurity Measurement Method	GRS0&2(Ge)	GRS0&2(Ge)	GRS0(Ge),LSC2	GRS0(Ge),LSC2
Radionuclidic Impurities Detected	Nb-93m	Eu-154	None	None
Relative Activity of the Impurity	7.1E-1	3.8E-3	-	-
Preparation of Master Solution	DIL	DIL	DIL	CAR,DIL
Preparation of SRM Solution	= Master	= Master	= Master	= Master
Preparation of Measurement Samples	GRV2	DIL5	GRV2	GRV2
Primary Measurement Model Type	LMNL	LMNL	LMNL	LMNL
Primary Measurement Method	CAC	PIC1(CPD)	LSC2+ET(H-3)	LSC2+ET(H-3)
Confirmatory Method(s)	CPD2(Ge)	CPD2(Ge)	None	None
Homogeneity Test	ALL	ALL	SEQ	SEQ
Other Information	[a]	[a]	-	-
Production Steps not Used	14,17,27	14,17,27	14,17,27	14,27

Appendix A1: Properties and Preparation of the NIST Radioactivity SRMs, as of January 2005.
Certified values are in bold type. Abbreviations and Notes are provided at the end of Appendix A1.

SRM Number	4233E	4234A	4241C	4251C
Radionuclide	**Cs-137**	**Sr-90**	**Ba-133**	**Ba-133**
Decay Mode(s) (>1%)	BP,GR	BP	EC,GR	EC,GR
Half Life	30.04 a	28.79 a	10.52 a	10.52 a
Intended Use	CAL(Ge,NaI)	CAL(LSC)	CAL(Ge,NaI)	CAL(Ge,NaI)
Physical State	Liquid	Liquid	Solid	Liquid
Chemical Form	CsCl	$SrCl_2$	$BaCl_2$	$BaCl_2$
Solution/Mixture Composition	1 M HCl	1 M HCl	-	1 M HCl
Solution/Mixture Mass (g)	**In preparation**	**5.063**	-	**5.054**
Solution density ($g \cdot mL^{-1}$)	**In preparation**	**1.015**	-	**1.015**
Containment	5NIST	5AMP	PSG	5NIST
Non-radioactive Carrier	CsCl	$SrCl_2$;YCl_3	$BaCl_2$	$BaCl_2$
Carrier Concentration ($mg \cdot L^{-1}$)	In preparation	500;600	~7 ug total	120
Massic Activity ($Bq \cdot g^{-1}$)	**~300 k**	**2.494 M**	**<140 kBq total***	**487.6 k**
Reference Time	**In preparation**	**13 Mar 1995**	**01 Jan 1999**	**01 Sep 1993**
Expanded Uncertainty (k=2) (%)	**In preparation**	**0.56**	**0.60**	**0.52**
Source of Starting Material(s)	PUR(COM)	PUR(COM)	PUR(COM)	PUR(COM)
Preparation of Starting Material(s)	None	None	None	None
Impurity Measurement Method	GRS0&2(Ge)	GRS2(Ge)	GRS0&2(Ge)	GRS0&2(Ge)
Radionuclidic Impurities Detected	None	Cs-137;Am-241	None	None
Relative Activity of the Impurity	-	6.E-6;2.E-6	-	-
Preparation of Master Solution	CAR,DIL	CAR,DIL	DIL	CAR,DIL
Preparation of SRM Solution	= Master	= Master	= Master	= Master
Preparation of Measurement Samples	None	GRV2	DIL5	None
Primary Measurement Model Type	LMNL	LMNL	LMNL	LMNL
Primary Measurement Method	PIC2(CAC)	LSC2+ET(H-3)	PIC1(CAC)	PIC2(CAC)
Confirmatory Method(s)	CPD2(Ge)	None	CPD2(Ge)	CDP2(Ge)
Homogeneity Test	In preparation	SEQ	ALL	ALL
Other Information	In preparation	-	[a]	-
Production Steps not Used	In preparation	14,27	14,17,27	14,27

Appendix A1: Properties and Preparation of the NIST Radioactivity SRMs, as of January 2005.
Certified values are in bold type. Abbreviations and Notes are provided at the end of Appendix A1.

SRM Number	4274	4288A	4320A	4321C
Radionuclide	**Ho-166m**	**Tc-99**	**Cm-244**	**U-NAT**
Decay Mode(s) (>1%)	BP,GR	BP	AP	AP
Half Life	1.20 ka	211 ka	18.1 a	4.468 Ga
Intended Use	CAL(Ge,NaI)	CAL,ENV	CAL,ENV	CAL,ENV
Physical State	Liquid	Liquid	Liquid	Liquid
Chemical Form	$HoCl_3$	$KTcO_4$	$Cm(NO_3)_3$	$UO_2(NO_3)_2$
Solution/Mixture Composition	1 M HCl	0.001 M KOH	1 M HNO_3	1 M HNO_3
Solution/Mixture Mass (g)	**In preparation**	**4.998**	~5	**5.258**
Solution density ($g \cdot mL^{-1}$)	**In preparation**	**0.998**	**1.030**	**1.053**
Containment	5NIST	5AMP	5AMP	5AMP
Non-radioactive Carrier	$HoCl_3$	None	None	None
Carrier Concentration ($mg \cdot L^{-1}$)	In preparation	-	-	-
Massic Activity ($Bq \cdot g^{-1}$)	**~20 k**	**32.61 k**	**37.06**	**486.2**
Reference Time	**In preparation**	**01 Sep 1996**	**01 Feb 1996**	**01 Aug 1997**
Expanded Uncertainty (k=2) (%)	**In preparation**	**1.14**	**0.68**	**0.78**
Source of Starting Material(s)	PUR(USDOE)	PUR(USDOE)	PUR(USDOE)	PUR(USDOE)
Preparation of Starting Material(s)	None	None	DSS	DSS
Impurity Measurement Method	GRS0&2(Ge)	GRS0&2(Ge)	GRS0(Ge),APS2	GRS1(Ge),APS2
Radionuclidic Impurities Detected	Tm-170	None	Pu-240;Cm-243	None
Relative Activity of the Impurity	In preparation	-	6.E-3;1.E-4	-
Preparation of Master Solution	DIL	DIL	DIL	QDIL
Preparation of SRM Solution	= Master	= Master	= Master	QDIL
Preparation of Measurement Samples	None	GRV2	GRV1	GRV1
Primary Measurement Model Type	LMNL	LMNL	LMNL	LMNL
Primary Measurement Method	PIC2(CAC)	CAC+ET(Co-60)	LSC1	WTR0,MS2
Confirmatory Method(s)	CPD2(Ge)	LSC2+ET(H-3)	LSC2	LSC2,SB
Homogeneity Test	In preparation	SEQ	SEQ	SEQ
Other Information	In preparation	-	-	-
Production Steps not Used	In preparation	14,27	14,27	27

Appendix A1: Properties and Preparation of the NIST Radioactivity SRMs, as of January 2005.
Certified values are in bold type. Abbreviations and Notes are provided at the end of Appendix A1.

SRM Number	4322B	4323B	4324B	4325C
Radionuclide	**Am-241**	**Pu-238**	**U-232**	**Be-10/9**
Decay Mode(s) (>1%)	AP,GR	AP	AP	BP
Half Life	432.2 a	87.7 a	68.9 a	1.51 Ma
Intended Use	CAL,ENV	CAL,ENV	CAL,ENV	AMS,GEO
Physical State	Liquid	Liquid	Liquid	Liquid
Chemical Form	$Am(NO_3)_3$	$Pu(NO_3)_6$	$UO_2(NO_3)_2$	$BeCl_2$
Solution/Mixture Composition	1 M HNO_3	3 M HNO_3	2 M HNO_3	1 M HCl
Solution/Mixture Mass (g)	~5.2	~5.5	**5.321**	~50
Solution density ($g \cdot mL^{-1}$)	**1.025**	**1.101**	**1.064**	Not given
Containment	5NIST	5AMP	5NIST	60TB
Non-radioactive Carrier	None	None	None	$BeCl_2$
Carrier Concentration ($mg \cdot L^{-1}$)	-	-	-	5 150 (as Be)
Massic Activity ($Bq \cdot g^{-1}$)	**39.24**	**41.52**	**38.22**	0.0002
Reference Time	**09 Sep 1991**	**15 Nov 1999**	**01 Jul 2002**	**Aug 1986**
Expanded Uncertainty (k=2) (%)	**0.95**	**0.68**	**0.80**	**5.1**
Source of Starting Material(s)	PUR(USDOE)	PUR(USDOE)	PUR(COM)	DON(USDOE)
Preparation of Starting Material(s)	DSS	DSS	None	DSS
Impurity Measurement Method	GRS0(Ge),APS2	GRS0(Ge),APS2	GRS0(Ge),APS1	GRS0&1(Ge)
Radionuclidic Impurities Detected	Pa-233	None	None	None
Relative Activity of the Impurity	8.E-6	-	-	-
Preparation of Master Solution	DIL	DIL	None	QDIL
Preparation of SRM Solution	QDIL	QDIL	QDIL	QDIL
Preparation of Measurement Samples	GRV1	GRV1	GRV1	GRV1
Primary Measurement Model Type	LMNL	LMNL	LMNL	LMNL
Primary Measurement Method	LSC1	LSC1	CAC	WTR0,MS0
Confirmatory Method(s)	LSC2	LSC2	PIC1(THE),CPR	AMS2,LSC0
Homogeneity Test	SEQ	SEQ	SEQ	None
Other Information	-	-	-	[e]
Production Steps not Used	27	27	27	7,8,17,21,27

Appendix A1: Properties and Preparation of the NIST Radioactivity SRMs, as of January 2005.
Certified values are in bold type. Abbreviations and Notes are provided at the end of Appendix A1.

SRM Number	4326	4328B	4329	4330A
Radionuclide	**Po-209**	**Th-229**	**Cm-243**	**Pu-239**
Decay Mode(s) (>1%)	AP	AP,GR	AP,GR	AP
Half Life	102 a	7.340 ka	29.1 a	24.110 ka
Intended Use	CAL,ENV	CAL,ENV	CAL,ENV	CAL,ENV
Physical State	Liquid	Liquid	Liquid	Liquid
Chemical Form	$PoCl_4$	$Th(NO_3)_4$	$Cm(NO_3)_3$	$Pu(NO_3)_6$
Solution/Mixture Composition	2 M HCl	1.1 M HNO_3	1 M HNO_3	3.1 M HNO_3
Solution/Mixture Mass (g)	**5.160**	**5.174**	**5.156**	~5.5
Solution density ($g \cdot mL^{-1}$)	**1.031**	**1.036**	Not given	**1.101**
Containment	5AMP	5NIST	5AMP	5AMP
Non-radioactive Carrier	None	None	None	None
Carrier Concentration ($mg \cdot L^{-1}$)	-	-	-	-
Massic Activity ($Bq \cdot g^{-1}$)	**85.42**	**33.36**	**69.50**	**39.24**
Reference Time	**15 Mar 1994**	**01 Jul 1996**	**13 Jun 1984**	**15 Nov 1999**
Expanded Uncertainty (k=2) (%)	**0.42**	**0.66**	**1.4**	**0.68**
Source of Starting Material(s)	PUR(COM)	PUR(USDOE)	PUR(USDOE)	PUR(USDOE)
Preparation of Starting Material(s)	None	None	DSS	DSS
Impurity Measurement Method	GRS0(Ge),APS1	GRS0(Ge)	GRS0(Ge),APS2	GRS0(Ge),APS2
Radionuclidic Impurities Detected	Po-208	None	Am-243;Cm-244	None
Relative Activity of the Impurity	1.E-3	-	8.E-4;8.E-4	-
Preparation of Master Solution	DIL	DIL	DIL	DIL
Preparation of SRM Solution	QDIL	QDIL	= Master	QDIL
Preparation of Measurement Samples	GRV1	GRV1	GRV1	GRV1
Primary Measurement Model Type	LMNL	LMNL	LMNL	LMNL
Primary Measurement Method	LSC1	DSA1,LSC1	DSA1	LSC1
Confirmatory Method(s)	GCE1,SB1	SB1,LSC2	None	LSC2
Homogeneity Test	SEQ	SEQ	None	SEQ
Other Information	-	-	-	-
Production Steps not Used	27	None	14,21,27	27

Appendix A1: Properties and Preparation of the NIST Radioactivity SRMs, as of January 2005.
Certified values are in bold type. Abbreviations and Notes are provided at the end of Appendix A1.

SRM Number	4332D	4334H	4337	4338A
Radionuclide	**Am-243**	**Pu-242**	**Pb-210**	**Pu-240**
Decay Mode(s) (>1%)	AP,GR	AP	BP,GR	AP
Half Life	7.370 ka	373.5 ka	22.2 a	6.564 ka
Intended Use	CAL,ENV	CAL,ENV	CAL,ENV	CAL,ENV
Physical State	Liquid	Liquid	Liquid	Liquid
Chemical Form	$Am(NO_3)_3$	$Pu(NO_3)_6$	$Pb(NO_3)_2$	$Pu(NO_3)_6$
Solution/Mixture Composition	1 M HNO_3	3.2 M HNO_3	1 M HNO_3	2.8 M HNO_3
Solution/Mixture Mass (g)	**5.143**	~5.5	**In preparation**	**5.471**
Solution density ($g \cdot mL^{-1}$)	**1.030**	**1.105**	**In Preparation**	**1.091**
Containment	5AMP	5AMP	5NIST	5AMP
Non-radioactive Carrier	None	None	$Pb(NO_3)_2$	None
Carrier Concentration ($mg \cdot L^{-1}$)	-	-	In preparation	-
Massic Activity ($Bq \cdot g^{-1}$)	**36.27**	**26.31**	**~10 k**	**40.88**
Reference Time	**19 May 1995**	**07 Jun 1994**	**In Preparation**	**01 May 1996**
Expanded Uncertainty (k=2) (%)	**0.78**	**0.72**	**In Preparation**	**0.76**
Source of Starting Material(s)	PUR(USDOE)	PUR(USDOE)	PUR(COM)	PUR(USDOE)
Preparation of Starting Material(s)	DSS	DSS	None	DSS
Impurity Measurement Method	GRS0(Ge),APS2	GRS1(Ge),APS2	GRS0&2(Ge)	GRS0(Ge),APS2
Radionuclidic Impurities Detected	Am-241	Pu-241	In preparation	Pu-238;Am-241
Relative Activity of the Impurity	2.E-3	3.5E-3	In preparation	9.E-3;2.E-4
Preparation of Master Solution	DIL	DIL	DIL	DIL
Preparation of SRM Solution	QDIL	QDIL	= Master	QDIL
Preparation of Measurement Samples	GRV1	GRV1	None	GRV1
Primary Measurement Model Type	LMNL	LMNL	LMNL	LMNL
Primary Measurement Method	DSA1	LSC1	CAC1	DSA1,LSC1
Confirmatory Method(s)	LSC2	LSC2	CPD2	LSC2
Homogeneity Test	SEQ	SEQ	In preparation	SEQ
Other Information	-	-	In preparation	-
Production Steps not Used	27	27	In preparation	27

Appendix A1: Properties and Preparation of the NIST Radioactivity SRMs, as of January 2005.
Certified values are in bold type. Abbreviations and Notes are provided at the end of Appendix A1.

SRM Number	4339A	4340A	4341	4342
Radionuclide	**Ra-228**	**Pu-241**	**Np-237**	**Th-230**
Decay Mode(s) (>1%)	BP	BP	AP,GR	AP
Half Life	5.75 a	14.35 a	2.14 Ma	75.38 ka
Intended Use	CAL,ENV	CAL,ENV	CAL,ENV	CAL,ENV
Physical State	Liquid	Liquid	Liquid	Liquid
Chemical Form	$Ra(NO_3)_2$	$Pu(NO_3)_6$	$Np(NO_3)_3$	$Th(NO_3)_4$
Solution/Mixture Composition	1 M HNO_3	2.8 M HNO_3	2 M HNO_3	1.3 M HNO_3
Solution/Mixture Mass (g)	**5.162**	~5.5	~5	~5.2
Solution density ($g \cdot mL^{-1}$)	**1.031**	**1.0895**	Not given	**1.043**
Containment	5NIST	5AMP	5AMP	5NIST
Non-radioactive Carrier	$Ba(NO_3)_2$	None	None	None
Carrier Concentration ($mg \cdot L^{-1}$)	80	-	-	-
Massic Activity ($Bq \cdot g^{-1}$)	**214.5**	**250.4**	**97.0**	**47.48**
Reference Time	**12 Apr 1994**	**02 Dec 1995**	**Mar 1992**	**08 Jun 1993**
Expanded Uncertainty (k=2) (%)	**2.20**	**1.06**	**1.28**	**0.58**
Source of Starting Material(s)	DON(NIST)	PUR(USDOE)	PUR(USDOE)	PUR(USDOE)
Preparation of Starting Material(s)	DSS,SEP	None	DSS	DSS,SEP
Impurity Measurement Method	GRS1(Ge)	GRS1(Ge),APS2	GRS0(Ge),APS1	GRS1,MS0
Radionuclidic Impurities Detected	Ra-226	None	None	Th-229;Th-232
Relative Activity of the Impurity	6.E-3	-	-	3E-4;5.E-7
Preparation of Master Solution	DIL	DIL	DIL	DIL
Preparation of SRM Solution	QDIL	QDIL	QDIL	QDIL
Preparation of Measurement Samples	GRV1&2	GRV1	GRV1	GRV1
Primary Measurement Model Type	LMNL	LMNL	LMNL	LMNL
Primary Measurement Method	CPD1	LSC1	DSA1	LSC1
Confirmatory Method(s)	CPD2	LSC2	None	LSC2
Homogeneity Test	SEQ	SEQ	None	SEQ
Other Information	-	-	-	-
Production Steps not Used	27	27	20,21,27	None

Appendix A1: Properties and Preparation of the NIST Radioactivity SRMs, as of January 2005.
Certified values are in bold type. Abbreviations and Notes are provided at the end of Appendix A1.

SRM Number	4350B	4351	4352
Radionuclide	See Appendix 2	See Appendix 2	See Appendix 2
Decay Mode(s) (>1%)	AP,BP,GR	AP	AP,GR
Half Life	2 a to 14 Ga	2 a to 14 Ga	2 a to 14 Ga
Intended Use	ENV	ENV	ENV
Physical State	Solid Powder	Solid Powder	Solid Powder
Chemical Form	Sediment	Animal Tissue	Animal Tissue
Solution/Mixture Composition	River Sediment	Human Lung	Human Liver
Solution/Mixture Mass (g)	85	45	45
Solution density ($g \cdot mL^{-1}$)	-	-	-
Containment	250PB	200SERUM	200SERUM
Non-radioactive Carrier	-	-	-
Carrier Concentration ($mg \cdot L^{-1}$)	-	-	-
Massic Activity ($Bq \cdot g^{-1}$)	See Appendix 2	See Appendix 2	See Appendix 2
Reference Time	**09 Sep 1981**	**01 Oct 1982**	**01 June 1982**
Expanded Uncertainty (k=2) (%)	**4 to 21**	**13 to 110**	**19 to 44**
Source of Starting Material(s)	DON(USDOE)	DON(USDOE)	DON(USDOE)
Preparation of Starting Material(s)	DRY,G/P,SC,BL,STZ	DRY,G/P,SC,BL,STZ	DRY,G/P,SC,BL,STZ
Impurity Measurement Method	-	-	-
Radionuclidic Impurities Detected	-	-	-
Relative Activity of the Impurity	-	-	-
Preparation of Master Solution	None	DIL,BL	DIL,BL
Preparation of SRM Solution	= Master	= Master	= Master
Preparation of Measurement Samples	GRV2	GRV2	GRV2
Primary Measurement Model Type	LMOL	LMOL	LMOL
Primary Measurement Method	APS2,BPS2,GRS2,MS	APS2	APS2
Confirmatory Method(s)	GRS2(Ge)	None	GRS2(Ge)
Homogeneity Test	RAN	RAN	RAN
Other Information	ELE,SIZ	SIZ	SIZ
Production Steps not Used	14,27	14,27	14,27

Appendix A1: Properties and Preparation of the NIST Radioactivity SRMs, as of January 2005.
Certified values are in bold type. Abbreviations and Notes are provided at the end of Appendix A1.

SRM Number	4353A	4354	4355
Radionuclide	See Appendix 2	See Appendix 2	See Appendix 2
Decay Mode(s) (>1%)	AP,BP,GR	AP,BP,GR	AP,BP,GR
Half Life	2 a to 14 Ga	2 a to 14 Ga	2 a to 14 Ga
Intended Use	ENV	ENV	ENV
Physical State	Solid Powder	Solid Powder	Solid Powder
Chemical Form	Soil	Sediment	Soil
Solution/Mixture Composition	RF Soil II	Lake Sediment	Peruvian Soil
Solution/Mixture Mass (g)	85	25	75
Solution density ($g \cdot mL^{-1}$)	-	-	-
Containment	250PB	250PB	250PB
Non-radioactive Carrier	-	-	-
Carrier Concentration ($mg \cdot L^{-1}$)	-	-	-
Massic Activity ($Bq \cdot g^{-1}$)	See Appendix 2	See Appendix 2	See Appendix 2
Reference Time	**In preparation**	**14 Feb 1986**	**01 Jun 1982**
Expanded Uncertainty (k=2) (%)	**In preparation**	**7 to 81**	**5 to 36**
Source of Starting Material(s)	DON(USDOE)	DON(USDOE)	DON(IAEA)
Preparation of Starting Material(s)	DRY,G/P,SC,BL,STZ	DRY,G/P,SC,BL,STZ	DRY,G/P,SC,BL,STZ
Impurity Measurement Method	-	-	-
Radionuclidic Impurities Detected	-	-	-
Relative Activity of the Impurity	-	-	-
Preparation of Master Solution	BL	BL	BL
Preparation of SRM Solution	= Master	= Master	= Master
Preparation of Measurement Samples	GRV2	GRV2	GRV2
Primary Measurement Model Type	LMOL	LMOL	LMNL
Primary Measurement Method	APS2,BPS2,GRS2	APS2,BPS2,GRS2	APS2,BPS2,GRS2
Confirmatory Method(s)	GRS2(Ge)	GRS2(Ge)	GRS2(Ge)
Homogeneity Test	RAN	RAN	RAN
Other Information	In preparation	ELE,SIZ	SIZ
Production Steps not Used	In preparation	14,27	14,27

Appendix A1: Properties and Preparation of the NIST Radioactivity SRMs, as of January 2005.
Certified values are in bold type. Abbreviations and Notes are provided at the end of Appendix A1.

SRM Number	4356	4357	4358
Radionuclide	See Appendix 2	See Appendix 2	See Appendix 2
Decay Mode(s) (>1%)	AP,BP,GR	AP,BP,GR	AP,BP,GR
Half Life	2 a to 14 Ga	2 a to 14 Ga	2 a to 14 Ga
Intended Use	ENV	ENV	ENV
Physical State	Solid Powder	Solid Powder	Solid Powder
Chemical Form	Ash	Sediment	Animal Tissue
Solution/Mixture Composition	Ashed Bone	Ocean Sediment	Ocean Shellfish
Solution/Mixture Mass (g)	15	85	75? x 2
Solution density ($g \cdot Ml^{-1}$)			-
Containment	60JAR	250PB	250PB x 2 + ALBAG
Non-radioactive Carrier	-	-	-
Carrier Concentration ($mg \cdot L^{-1}$)	-	-	-
Massic Activity ($Bq \cdot g^{-1}$)	See Appendix 2	See Appendix 2	See Appendix 2
Reference Time	**31 Dec 1995**	**16 Feb 1994**	**In preparation**
Expanded Uncertainty (k=2) (%)	**13 to 71**	**10 to 91**	**In preparation**
Source of Starting Material(s)	DON(USDOE)	DON(IAEA)	DON(IAEA)
Preparation of Starting Material(s)	DRY,G/P,SC,BL,STZ	DRY,G/P,SC,BL,STZ	DRY,G/P,SC,BL,STZ
Impurity Measurement Method	-	-	-
Radionuclidic Impurities Detected	-	-	-
Relative Activity of the Impurity	-	-	-
Preparation of Master Solution	DIL,BL	DIL,BL	DIL,BL
Preparation of SRM Solution	= Master	= Master	= Master
Preparation of Measurement Samples	GRV2	GRV2	GRV2
Primary Measurement Model Type	LMOL	LMNL,LMOL	LMOL
Primary Measurement Method	APS2,BPS2,GRS2	APS2,BPS2,GRS2	APS2,BPS2,GRS2
Confirmatory Method(s)	GRS2(Ge)	GRS2(Ge)	GRS2(Ge)
Homogeneity Test	RAN	RAN	RAN
Other Information	-	ELE,SIZ	In preparation
Production Steps not Used	14,27	14,27	In preparation

Appendix A1: Properties and Preparation of the NIST Radioactivity SRMs, as of January 2005.
Certified values are in bold type. Abbreviations and Notes are provided at the end of Appendix A1.

SRM Number	4359		
Radionuclide	See Appendix 2		
Decay Mode(s) (>1%)	AP,BP,GR		
Half Life	2 a to 14 Ga		
Intended Use	ENV		
Physical State	Solid Powder		
Chemical Form	Vegetation		
Solution/Mixture Composition	Seaweed		
Solution/Mixture Mass (g)	?		
Solution density ($g \cdot Ml^{-1}$)	-		
Containment	500GB		
Non-radioactive Carrier	-		
Carrier Concentration ($mg \cdot L^{-1}$)	-		
Massic Activity ($Bq \cdot g^{-1}$)	See Appendix 2		
Reference Time	**In preparation**		
Expanded Uncertainty (k=2) (%)	**In preparation**		
Source of Starting Material(s)	DON(IAEA)		
Preparation of Starting Material(s)	DRY,G/P,SC,BL,STZ		
Impurity Measurement Method	-		
Radionuclidic Impurities Detected	-		
Relative Activity of the Impurity	-		
Preparation of Master Solution	DIL,BL		
Preparation of SRM Solution	= Master		
Preparation of Measurement Samples	GRV2		
Primary Measurement Model Type	LMNL,LMOL		
Primary Measurement Method	APS2,BPS2,GRS2		
Confirmatory Method(s)	GRS2(Ge)		
Homogeneity Test	RAN		
Other Information	In preparation		
Production Steps not Used	In preparation		

Appendix A1: Properties and Preparation of the NIST Radioactivity SRMs, as of January 2005.
Certified values are in bold type. Abbreviations and Notes are provided at the end of Appendix A1.

SRM Number	4361C	4370C	4401H	4401L
Radionuclide	H-3	**Eu-152**	**I-131**	**I-131**
Decay Mode(s) (>1%)	BP	BP,EC,GR	BP,GR	BP,GR
Half Life	12.32 a	13.537 a	8.02070 d	8.02070 d
Intended Use	HYD	CAL(Ge,NaI)	CAL,NM	CAL,NM
Physical State	Liquid	Liquid	Liquid	Liquid
Chemical Form	H_2O	$EuCl_3$	KI	KI
Solution/Mixture Composition	H_2O	1 M Hcl	0.008 M LiOH+	0.007 M LiOH+
Solution/Mixture Mass (g)	~500	**5.0338**	**4.9420***	**4.9744***
Solution density ($g \cdot Ml^{-1}$)	**0.998**	Not given	**0.999**	**0.999**
Containment	500GB	5NIST	5NIST	5NIST
Non-radioactive Carrier	None	$EuCl_3$	KI	KI
Carrier Concentration ($mg \cdot L^{-1}$)	-	277	600	70
Massic Activity ($Bq \cdot g^{-1}$)	**2.009**	**93.90 k**	**206.8 M**	**5.365 M**
Reference Time	**03 Sep 1998**	**02 Feb 1987**	**every Jan**	**every Jan**
Expanded Uncertainty (k=2) (%)	**0.76**	**1.1**	**0.70**	**0.70**
Source of Starting Material(s)	PUR(COM)	PUR(USDOE)	PUR(COM)	PUR(COM)
Preparation of Starting Material(s)	None	None	None	None
Impurity Measurement Method	GRS0(Ge),BPS1	GRS1(Ge)	GRS2(Ge)	GRS1&2(Ge)
Radionuclidic Impurities Detected	None	Eu-154	None	None
Relative Activity of the Impurity	-	2.9E-3	-	-
Preparation of Master Solution	= 4926E	CAR,DIL	CAR,DIL	= 4401H
Preparation of SRM Solution	QDIL	= Master	= Master	CAR,QDIL
Preparation of Measurement Samples	GRV2	None	None	None
Primary Measurement Model Type	LMNL	LMNL	LMNL	LMNL
Primary Measurement Method	GCI	PIC1(CPD)	PIC1(CAC)	PIC1&2(CAC)
Confirmatory Method(s)	LSC2	CPD2(Ge)	CPD2(Ge)	CDP2(Ge)
Homogeneity Test	SEQ	ALL	ALL	ALL
Other Information	[e]	-	-	-
Production Steps not Used	17, 27	27	None	None

Appendix A1: Properties and Preparation of the NIST Radioactivity SRMs, as of January 2005.
Certified values are in bold type. Abbreviations and Notes are provided at the end of Appendix A1.

SRM Number	4404H	4404L	4407H	4407L
Radionuclide	**Tl-201**	**Tl-201**	**I-125**	**I-125**
Decay Mode(s) (>1%)	EC,GR	EC,GR	EC,GR	EC,GR
Half Life	72.912 h	72.912 h	59.400 d	59.400 d
Intended Use	CAL,NM	CAL,NM	CAL,NM	CAL,NM
Physical State	Liquid	Liquid	Liquid	Liquid
Chemical Form	$TlNO_3$	$TlNO_3$	KI	KI
Solution/Mixture Composition	1.2 M HNO_3	1.2 HNO_3	0.07 M LiOH	0.01 M LiOH
Solution/Mixture Mass (g)	**5.3317***	**5.2051***	**5.1459***	**4.9608***
Solution density ($g \cdot Ml^{-1}$)	**1.039**	**1.040**	**1.007**	**0.999**
Containment	5NIST	5NIST	5NIST	5NIST
Non-radioactive Carrier	$TlNO_3$	$TlNO_3$	KI	KI
Carrier Concentration ($mg \cdot L^{-1}$)	200	100	5000	60
Massic Activity ($Bq \cdot g^{-1}$)	**67.22 M**	**5.858 M**	**211.0 M**	**1.433 M**
Reference Time	**every Jun**	**every Jun**	**every Dec**	**every Dec**
Expanded Uncertainty (k=2) (%)	**0.80**	**0.80**	**0.78**	**0.78**
Source of Starting Material(s)	PUR(COM)	PUR(COM)	PUR(COM)	PUR(COM)
Preparation of Starting Material(s)	None	None	None	None
Impurity Measurement Method	GRS2(Ge)	GRS1&2(Ge)	GRS2(Ge)	GRS1&2(Ge)
Radionuclidic Impurities Detected	Tl-200;Tl-202	Tl-200;Tl-202	None	None
Relative Activity of the Impurity	2.E-3;2.E-3	2.E-3;2.E-3	-	-
Preparation of Master Solution	CAR,DIL	= 4404H	DIL	= 4407H
Preparation of SRM Solution	= Master	CAR,QDIL	= Master	CAR,QDIL
Preparation of Measurement Samples	None	None	GRV2	GRV2
Primary Measurement Model Type	LMNL	LMNL	LMNL	LMNL
Primary Measurement Method	PIC1(CAC)	PIC1&2(CAC)	SPC2	SPC
Confirmatory Method(s)	CPD2(Ge)	CPD2(Ge)	CPD2(Ge)	CDP2(Ge)
Homogeneity Test	ALL	ALL	ALL	ALL
Other Information	-	-	-	-
Production Steps not Used	14,27	27	14,27	27

Appendix A1: Properties and Preparation of the NIST Radioactivity SRMs, as of January 2005.
Certified values are in bold type. Abbreviations and Notes are provided at the end of Appendix A1.

SRM Number	4410H		4412H	4412L
Radionuclide	**Tc-99m**		**Mo-99**	**Mo-99**
Decay Mode(s) (>1%)	IT,GR		BP,GR	BP,GR
Half Life	6.01 h		65.94 h	65.94 h
Intended Use	CAL,NM		CAL,NM	CAL,NM
Physical State	Liquid		Liquid	Liquid
Chemical Form	$NaTcO_4$		Na_2MoO_4	Na_2MoO_4
Solution/Mixture Composition	0.16 M NaCl		3.1M HNO_3	3.1M HNO_3
Solution/Mixture Mass (g)	**4.9865***		**5.4834***	**5.5053***
Solution density ($g \cdot Ml^{-1}$)	**1.005**		**1.102**	**1.102**
Containment	5NIST		5NIST	5NIST
Non-radioactive Carrier	None		Na_2MoO_4	Na_2MoO_4
Carrier Concentration ($mg \cdot L^{-1}$)	-		1000	90
Massic Activity ($Bq \cdot g^{-1}$)	**1.408 G**		**353.9 M**	**15.22 M**
Reference Time	**every May**		**every Feb**	**every Feb**
Expanded Uncertainty (k=2) (%)	**0.64**		**0.72**	**0.72**
Source of Starting Material(s)	PUR(COM)		PUR(COM)	PUR(COM)
Preparation of Starting Material(s)	None		None	None
Impurity Measurement Method	GRS2(Ge)		GRS2(Ge)	GRS1&2(Ge)
Radionuclidic Impurities Detected	Mo-99		None	None
Relative Activity of the Impurity	1.E-6		-	-
Preparation of Master Solution	DIL		CAR,DIL	= 4412H
Preparation of SRM Solution	= Master		= Master	CAR,QDIL
Preparation of Measurement Samples	None		None	None
Primary Measurement Model Type	LMNL		LMNL	LMNL
Primary Measurement Method	PIC1(CAC)		PIC1(CAC)	PIC1&2(CAC)
Confirmatory Method(s)	CPD2(Ge)		CPD2(Ge)	CDP2(Ge)
Homogeneity Test	ALL		ALL	ALL
Other Information	-		-	-
Production Steps not Used	14,27		14,27	27

Appendix A1: Properties and Preparation of the NIST Radioactivity SRMs, as of January 2005.
Certified values are in bold type. Abbreviations and Notes are provided at the end of Appendix A1.

SRM Number	4415H	4415L	4416H	4416L
Radionuclide	**Xe-133**	**Xe-133**	**Ga-67**	**Ga-67**
Decay Mode(s) (>1%)	BP,GR	BP,GR	EC,GR	EC,GR
Half Life	5.243 d	5.243 d	3.2612 d	3.2612 d
Intended Use	CAL,NM	CAL,NM	CAL,NM	CAL,NM
Physical State	Gas	Gas	Liquid	Liquid
Chemical Form	Xe	Xe	$GaCl_3$	$GaCl_3$
Solution/Mixture Composition	Xe	Xe	2 M Hcl	2 M Hcl
Solution/Mixture Mass (g)	~20 mg total	~7 mg total	**5.0180***	**5.1523***
Solution density ($g \cdot Ml^{-1}$)	~75 kPa	~25 Kpa	**1.033**	**1.033**
Containment	5GAS	5GAS	5NIST	5NIST
Non-radioactive Carrier	None	None	$GaCl_3$	$GaCl_3$
Carrier Concentration ($mg \cdot L^{-1}$)	-		800	800
Massic Activity ($Bq \cdot g^{-1}$)	**7.560 G total***	**563.8 M total***	**89.88 M**	**4.688 M**
Reference Time	**every Sep**	**every Sep**	**every Apr**	**every Apr**
Expanded Uncertainty (k=2) (%)	**0.78**	**0.78**	**0.60**	**0.60**
Source of Starting Material(s)	PUR(COM)	PUR(COM)	PUR(COM)	PUR(COM)
Preparation of Starting Material(s)	None	None	None	None
Impurity Measurement Method	GRS2(Ge)	GRS1&2(Ge)	GRS2(Ge)	GRS1&2(Ge)
Radionuclidic Impurities Detected	Kr-85;Xe-131m	Kr-85;Xe-131m	None	None
Relative Activity of the Impurity	4.E-6;1.5E-2	5.E-6;1.5E-2	-	-
Preparation of Master Solution	CAR,DIL	= 4415H	CAR,DIL	= 4416H
Preparation of SRM Solution	= Master	CAR,QDIL	= Master	CAR,QDIL
Preparation of Measurement Samples	None	None	None	None
Primary Measurement Model Type	LMNL	LMNL	LMNL	LMNL
Primary Measurement Method	PIC1(GCI)	PIC1&2(GCI)	PIC1(CAC)	PIC1&2(CAC)
Confirmatory Method(s)	CPD2(Ge)	CPD2(Ge)	CPD2(Ge)	CDP2(Ge)
Homogeneity Test	Not applicable	Not applicable	ALL	ALL
Other Information	-	-	-	-
Production Steps not Used	14,17,21,27	17,21,27	14,27	27

Appendix A1: Properties and Preparation of the NIST Radioactivity SRMs, as of January 2005.
Certified values are in bold type. Abbreviations and Notes are provided at the end of Appendix A1.

SRM Number	4417H	4417L	4427H	4427L
Radionuclide	**In-111**	**In-111**	**Y-90**	**Y-90**
Decay Mode(s) (>1%)	EC,GR	EC,GR	BP	BP
Half Life	2.8047 d	2.8047 d	64.0 h	64.0 h
Intended Use	CAL,NM	CAL,NM	CAL,NM	CAL,NM
Physical State	Liquid	Liquid	Liquid	Liquid
Chemical Form	$InCl_3$	$InCl_3$	YCl_3	YCl_3
Solution/Mixture Composition	2.8 M HCl	3.2 M HCl	1.1 M HCl	1.1 M HCl
Solution/Mixture Mass (g)	**5.235***	**5.265***	**5.0200***	**5.0844***
Solution density ($g \cdot mL^{-1}$)	**1.047**	**1.053**	**1.017**	**1.017**
Containment	5NIST	5NIST	5NIST	5NIST
Non-radioactive Carrier	$InCl_3$	$InCl_3$	YCl_3	YCl_3
Carrier Concentration ($mg \cdot L^{-1}$)	500	60	50	50
Massic Activity ($Bq \cdot g^{-1}$)	**64.23 M**	**6.224 M**	**74.73 M**	**5.731 M**
Reference Time	**every Aug**	**every Aug**	**every Oct**	**every Oct**
Expanded Uncertainty (k=2) (%)	**0.54**	**0.54**	**0.72**	**0.72**
Source of Starting Material(s)	PUR(COM)	PUR(COM)	PUR(COM)	PUR(COM)
Preparation of Starting Material(s)	None	None	None	None
Impurity Measurement Method	GRS2(Ge)	GRS1&2(Ge)	GRS2(Ge)	GRS1&2(Ge)
Radionuclidic Impurities Detected	In-114m	In-114m	Sr-90	Sr-90
Relative Activity of the Impurity	3.E-4	3.E-4	7.E-8	7.E-8
Preparation of Master Solution	CAR,DIL	= 4417H	CAR,DIL	= 4427H
Preparation of SRM Solution	= Master	CAR,QDIL	= Master	CAR,QDIL
Preparation of Measurement Samples	None	None	GRV2	GRV2
Primary Measurement Model Type	LMNL	LMNL	LMNL	LMNL
Primary Measurement Method	PIC1(CAC)	PIC1&2(CAC)	LSC2	LSC2
Confirmatory Method(s)	CPD2(Ge)	CPD2(Ge)	PIC2(LSC)	PIC2(LSC)
Homogeneity Test	ALL	ALL	ALL	ALL
Other Information	-	-	-	-
Production Steps not Used	14,27	27	14,27	27

Appendix A1: Properties and Preparation of the NIST Radioactivity SRMs, as of January 2005.
Certified values are in bold type. Abbreviations and Notes are provided at the end of Appendix A1.

SRM Number	4915E	4919H	4926E	4927F
Radionuclide	**Co-60**	**Sr-90**	**H-3**	**H-3**
Decay Mode(s) (>1%)	BP,GR	BP	BP	BP
Half Life	5.2712 a	28.79 a	12.32 a	12.32 a
Intended Use	CAL(Ge,NaI)	CAL(LSC)	CAL(LSC),HYD	CAL(LSC)
Physical State	Liquid	Liquid	Liquid	Liquid
Chemical Form	$CoCl_2$	$SrCl_2$	H_2O	H_2O
Solution/Mixture Composition	1 M HCl	0.9 M HCl	H_2O	H_2O
Solution/Mixture Mass (g)	**5.063**	~5.0	~20	~5.0
Solution density ($g \cdot mL^{-1}$)	**1.016**	**1.014**	**0.998**	**0.998**
Containment	5NIST	5AMP	20SERUM	5AMP
Non-radioactive Carrier	$CoCl_2$	$SrCl_2$;YCl_3	None	None
Carrier Concentration ($mg \cdot L^{-1}$)	100	200;200	-	-
Massic Activity ($Bq \cdot g^{-1}$)	**75.55 k**	**4.010 k**	**5.038 k**	**634.7 k**
Reference Time	**01 Jan 1995**	**01 Jul 1995**	**03 Sep 1998**	**03 Sep 1998**
Expanded Uncertainty (k=2) (%)	**0.54**	**0.74**	**0.72**	**0.72**
Source of Starting Material(s)	PUR(COM)	PUR(COM)	PUR(COM)	PUR(COM)
Preparation of Starting Material(s)	None	None	None	None
Impurity Measurement Method	GRS2(Ge)	GRS1(Ge)	GRS0(Ge),BPS0	GRS0(Ge),BPS1
Radionuclidic Impurities Detected	None	None	None	None
Relative Activity of the Impurity	-	-	-	-
Preparation of Master Solution	CAR,DIL	= 4234A	=4927F	DIL
Preparation of SRM Solution	= Master	CAR,QDIL	QDIL	=Master
Preparation of Measurement Samples	None	GRV2	GRV2	GRV2
Primary Measurement Model Type	LMNL	LMNL	LMNL	LMNL
Primary Measurement Method	PIC2(CAC)	LSC2+ET(H-3)	GCI1	GCI2
Confirmatory Method(s)	CPD2(Ge)	None	LSC2	LSC2
Homogeneity Test	ALL	SEQ	SEQ	SEQ
Other Information	-	-	-	-
Production Steps not Used	14,27	27	17,27	14,27

Appendix A1: Properties and Preparation of the NIST Radioactivity SRMs, as of January 2005.
Certified values are in bold type. Abbreviations and Notes are provided at the end of Appendix A1.

SRM Number	4929E	4943	4947C	4949C
Radionuclide	**Fe-55**	**Cl-36**	**H-3**	**I-129**
Decay Mode(s) (>1%)	EC	BP,EC	BP	BP,GR
Half Life	2.737 a	301 ka	12.32 a	15.7 Ma
Intended Use	CAL(LSC),ENV	CAL(LSC),ENV	CAL(LSC)	ENV,CAL(LSC)
Physical State	Liquid	Liquid	Liquid	Liquid
Chemical Form	$FeCl_2$	NaCl	Toluene	NaI
Solution/Mixture Composition	1 M HCl	H_2O	Toluene	0.01 M NaOH+
Solution/Mixture Mass (g)	**In preparation**	~3	~4	~5.0
Solution density ($g \cdot mL^{-1}$)	**In preparation**	Not given	**0.8669**	**1.003**
Containment	5AMP	5AMP	5AMP	5AMP
Non-radioactive Carrier	$FeCl_2$	NaCl	None	None
Carrier Concentration ($mg \cdot L^{-1}$)	In preparation	200	-	-
Massic Activity ($Bq \cdot g^{-1}$)	**~30 k**	**10.95 k**	**308.1 k**	**3.451 k**
Reference Time	**In preparation**	**Dec 1984**	**04 Mar 1987**	**21 Mar 1993**
Expanded Uncertainty (k=2) (%)	**In preparation**	**0.82**	**1.2**	**0.64**
Source of Starting Material(s)	PUR(COM)	PUR(COM)	PUR(COM)	PUR(COM)
Preparation of Starting Material(s)	None	None	None	None
Impurity Measurement Method	GRS1&2(Ge)	GRS0(Ge),BPS2	GRS1(Ge),BPS2	GRS1(Ge),BPS2
Radionuclidic Impurities Detected	In preparation	None	None	None
Relative Activity of the Impurity	In preparation	-	-	-
Preparation of Master Solution	CAR,DIL	DIL	DIL	DIL
Preparation of SRM Solution	CAR,QDIL	=Master	=Master	CAR,QDIL
Preparation of Measurement Samples	GRV2	GRV2	GRV2	GRV2
Primary Measurement Model Type	LMNL	LMNL	LMNL	LMNL
Primary Measurement Method	DSA1	GCE1	LSC2	CAC1
Confirmatory Method(s)	In preparation	LSC2	None	LSC2
Homogeneity Test	In preparation	SEQ	SEQ	SEQ
Other Information	In preparation	-	-	-
Production Steps not Used	In preparation	14,27	14,17,27	27

Appendix A1: Properties and Preparation of the NIST Radioactivity SRMs, as of January 2005.
Certified values are in bold type. Abbreviations and Notes are provided at the end of Appendix A1.

SRM Number	4965	4966	4967A	4969
Radionuclide	**Ra-226**	**Ra-226**	**Ra-226**	**Ra-226**
Decay Mode(s) (>1%)	AP,GR	AP,GR	AP,GR	AP,GR
Half Life	1.600 ka	1.600 ka	1.600 ka	1.600 ka
Intended Use	CAL,ENV	CAL,ENV	CAL,ENV	CAL,ENV
Physical State	Liquid	Liquid	Liquid	Liquid
Chemical Form	$RaCl_2$	$RaCl_2$	$RaCl_2$	$RaCl_2$
Solution/Mixture Composition	1.4 M HCl	1.4 M HCl	1 M HCl	1.5 M HCl
Solution/Mixture Mass (g)	**5.098**	**5.1138**	**5.086**	**5.122**
Solution density ($g \cdot mL^{-1}$)	**1.019**	**1.020**	**1.017**	**1.024**
Containment	5NIST	5NIST	5NIST	5NIST
Non-radioactive Carrier	$BaCl_2$	$BaCl_2$	$BaCl_2$	$BaCl_2$
Carrier Concentration ($mg \cdot L^{-1}$)	1700	1670	80	100
Massic Activity ($Bq \cdot g^{-1}$)	**30.99**	**268.2**	**2.482 k**	**3.047**
Reference Time	**09 Sep 1991**	**09 Sep 1991**	**01 Sep 2003**	**15 Sep 1998**
Expanded Uncertainty (k=2) (%)	**1.23**	**1.19**	**1.20**	**1.8**
Source of Starting Material(s)	PUR(COM)	PUR(COM)	PUR(COM)	PUR(COM)
Preparation of Starting Material(s)	None	None	None	None
Impurity Measurement Method	GRS0&1(Ge)	GRS0&1(Ge)	GRS0&1(Ge)	GRS0&1(Ge)
Radionuclidic Impurities Detected	None	None	None	None
Relative Activity of the Impurity	-	-	-	-
Preparation of Master Solution	CAR,QDIL	CAR,QDIL	CAR,QDIL	CAR,QDIL
Preparation of SRM Solution	CAR,QDIL	CAR,QDIL	CAR,QDIL	CAR,QDIL
Preparation of Measurement Samples	GRV2	GRV2	GRV2	GRV2
Primary Measurement Model Type	LMNL	LMNL	LMNL	LMNL
Primary Measurement Method	WTR0	WTR0	WTR0	WTR0
Confirmatory Method(s)	LSC2	LSC2	LSC2	LSC2
Homogeneity Test	PIC2,CPD2	PIC2,CPD2	PIC2,CPD2	PIC2,CPD2
Other Information	-	-	-	-
Production Steps not Used	27	27	27	27

Appendix A1: Properties and Preparation of the NIST Radioactivity SRMs, as of January 2005.
Certified values are in bold type. Abbreviations and Notes are provided at the end of Appendix A1.

SRM Number	4971	4972	4973	4990C
Radionuclide	**Ra-226**	**Ra-226**	**Ra-226**	**C-14**
Decay Mode(s) (>1%)	AP,GR	AP,GR	AP,GR	BP
Half Life	1.600 ka	1.600 ka	1.600 ka	5.70 ka
Intended Use	RN222	RN222	RN222	C14
Physical State	Liquid	Liquid	Liquid	Solid
Chemical Form	$RaCl_2$	$RaCl_2$	$RaCl_2$	Oxalic Acid
Solution/Mixture Composition	1 M HCl	1 M HCl	1 M HCl	Powder
Solution/Mixture Mass (g)	~0.2	~0.2	~0.2	28 x 8
Solution density ($g \cdot mL^{-1}$)	1.015	1.015	1.015	-
Containment	POLY	POLY	POLY	60JAR x 8
Non-radioactive Carrier	$BaCl_2$	$BaCl_2$	$BaCl_2$	None
Carrier Concentration ($mg \cdot L^{-1}$)	In preparation	In preparation	In preparation	-
Massic Activity ($Bq \cdot g^{-1}$)	**~4 Bq total***	**~40 Bq total***	**~400 Bq total***	**0.008**
Reference Time	**In preparation**	**In preparation**	**In preparation**	**1980**
Expanded Uncertainty (k=2) (%)	**In preparation**	**In preparation**	**In preparation**	**1.6**
Source of Starting Material(s)	PUR(COM)	PUR(COM)	PUR(COM)	PUR(COM)
Preparation of Starting Material(s)	None	None	None	None
Impurity Measurement Method	GRS0(Ge)	GRS0(Ge)	GRS0(Ge)	GRS0(Ge)
Radionuclidic Impurities Detected	None	None	None	None
Relative Activity of the Impurity	-	-	-	-
Preparation of Master Solution	CAR,QDIL	CAR,QDIL	CAR,QDIL	OA
Preparation of SRM Solution	CAR,QDIL	CAR,QDIL	CAR,QDIL	OA
Preparation of Measurement Samples	GRV2	GRV2	GRV2	OA
Primary Measurement Model Type	LMNL	LMNL	LMNL	LMNL
Primary Measurement Method	WTR0	WTR0	WTR0	GCI2
Confirmatory Method(s)	LSC2	LSC2	LSC2	LSC2
Homogeneity Test	ALL	ALL	ALL	RAN
Other Information	[c]	[c]	[c]	[d],[e]
Production Steps not Used	In preparation	In preparation	In preparation	-

ABBREVIATIONS AND ACRONYMS

General
* = Representative value; Each unit is individually measured and certified.
+ = Solution also contains other components. See the SRM Certificate for more information.

Decay Modes
AP = Alpha-Particle emission
BP = Beta-Particle emission
EC = Electron Capture
GR = Gamma-Ray emission
IT = Internal Transition

Intended Use
AMS = Accelerator Mass Spectrometry
CAL( ) = Calibration of instruments ( ) and procedures
C14 = Carbon-14 dating measurements
ENV = Environmental measurements
GEO = Geological and geochronological measurements
HYD = Hydrological measurements
NM = Nuclear Medicine
RN222 = Radon-222 measurements

Containment - See the Appendices for more information
200SERUM = 300 mL glass serum bottle
20SERUM = 20 mL glass serum vial
250PB = 250 mL wide-mouth plastic bottle
500GB = 500 mL glass bottle
5AMP = 5 mL standard glass ampoule
5GAS = 5 ml gas ampoule [b]
5NIST = 5 mL NIST glass ampoule
60JAR = 60 mL glass jar
60TB = 60 mL teflon bottle
ALBAG = Heat-sealed aluminized Mylar bag
POLY = Polyethylene capsule [c]
PSG = Point Source for Gamma-ray emitters [a]

Source of Starting Material - See the Appendices for more information
COM = Commercial supplier
DON ( ) = Donated by ( )
IAEA = International Atomic Energy Agency
PUR ( ) = Purchased from ( )
USDOE = United States Department of Energy

Preparation of Starting Material(s) - See the Appendices for more information
BL = Blending
DRY = Drying
DSS = Dissolution of solid material(s)
G/P = Grinding / Pulverizing
SC = Screening
SEP = Radiochemical Separation / Purification
STZ = Sterilization

Measurement Methods - See the Appendices for more information
0 = Starting material
1 = Material from the Master Solution
2 = Material from the SRM container
AC = Atom Counting
APS = Alpha-particle Spectrometry
BPS = Beta-particle Spectrometry
CAC = Coincidence/Anticoincidence Counting
CPD( ) = Calibrated Photon Detection System (Ge, NaI, etc.)

CPR = Compared with previous RSRM
DSA = Defined Solid Angle Counting
ET( ) = Efficiency Tracing using ( ) as the tracing radionuclide
GCE = Gas Counting (External)
GCI = Gas Counting (Internal)
Ge = Germanium photon detector
GRS( ) = Gamma-ray Spectrometry using ( )
LSC = Liquid Scintillation Counting
MS = Mass Spectrometry
NaI = Sodium Iodide photon detector
OA = Other Agency. Distributed but not certified by NIST.
PIC( ) = Ionization Chamber calibrated using ( )
SB = Surface Barrier alpha-particle detector
SPC = Sum-Peak Counting
THE = Theoretically Computed
WTR = Weight of Radionuclide

Preparation of Solutions/Mixtures - See the Appendices for more information
BL = Blending
CAR = Addition of non-radioactive carrier
DIL = Dilution
DIL5 = Dilution to (5.0 ± 0.1) mL in a 5 mL NIST ampoule
QDIL = Quantitative dilution

Preparation of Measurement Samples - See the Appendices for more information
0 = Starting material
1 = Material from the Master Solution
2 = Material from the SRM container
DIL5 = Dilution to (5.0 ± 0.1) mL in a 5 mL NIST ampoule
GRV = Dispense by mass
QDIL = Quantitative dilution

Measurement Models - See the Appendices for more information
LMNL = Linear, Multiplicative, Normal Distribution, Low Correlation
LMNH = Linear, Multiplicative, Normal Distribution, High Correlation
LMOL = Linear, Multiplicative, Other than Normal Distribution, Low Correlation
NMNL = Non-Linear, Multiplicative, Normal Distribution, Low Correlation

Homogeneity Test - See the Appendices for more information
ALL = Measure every SRM dispensed
SEQ = Measure sequential samples of the SRM (typically the first, some of the middle, and the last dispensed)
RAN = Measure SRMs randomly selected out of the total dispensed

Other Information
ELE = Semi-quantitative elemental analysis
SIZ = Particle size distribution
[letter] = Note
[number] = Reference

NOTES

[a] The standard consists of a dried deposit, usually with a diameter of less than 0.5 cm, of the radionuclide sealed between two layers of 0.006 cm thick polyester tape that are supported on an aluminum annulus. The annulus has an outside diameter of 5.4 cm, an inside diameter of 3.8 cm, and a thickness of 0.05 cm.

[b] Flame-sealed borosilicate glass ampoule with an outside diameter of 1.5 cm and a length of 4.5 cm.

[c] SRMs 4971, 4972, and 4973 are intended for the calibration of radon-222 measuring instruments. They consist of small heat-sealed polyethylene cylinders containing approximately 0.2 g of radium-226 solution. These SRMs are calibrated in terms of radium-226 activity and in terms of the emanation fraction of radon-222 under specified conditions.

[d] SRM 4990C replaces SRM 4990, which has been in use in radiocarbon dating laboratories since 1958. The material is part of a 450 kg lot of oxalic acid that was prepared by fermentation of French beet molasses from the 1977 spring, summer, and fall harvests. The ratio of the massic activity of SRM 4990C to that of SRM 4990, and the isotopic ratios of carbon-13 to carbon-12 in each, were measured by eleven international carbon dating laboratories in an intercomparison organized by L.M. Cavallo and W.B. Mann. See Proceedings of the 11th International Radiocarbon Dating Conference, M. Stuiver and R. Kra, Editors, *Radiocarbon* **25**, No. 2 (1983).

[e] This standard is not radioactive material for licensing or shipping purposes.

Appendix A2: Radionuclides and Massic Activities in the Natural Matrix radioactivity SRMs (see IRD Procedure 16)

SRM Number	4350B	4351	4352	4353A	4354
Description	River Sediment	Human Lung	Human Liver	RF Soil II	Lake Sediment
Radionuclide	Massic Activity ($mBq \cdot g^{-1}$) **Certified values are in bold type**.				
^{40}K	560.	-	-	In preparation	-
^{55}Fe	17.	-	-	-	-
^{60}Co	**4.64**	-	-	-	**320.**
^{90}Sr	5.3	-	-	-	**1090.**
^{129}I	-	-	-	-	-
^{137}Cs	**29.0**	-	-	-	**59.2**
^{152}Eu	**30.5**	-	-	-	-
^{154}Eu	**3.78**	-	-	-	-
^{155}Eu	-	-	-	-	-
^{208}Tl	-	-	-	-	-
^{210}Po	-	-	-	-	-
^{210}Pb	-	-	-	-	120.
^{212}Pb	-	-	-	-	-
^{214}Bi	-	-	-	-	-
^{226}Ra	**35.8**	-	-	-	30.
^{228}Ra	-	-	-	-	-
^{228}Ac	-	-	-	-	-
^{228}Th	33.5	0.22	0.51	-	**28.6**
^{230}Th	29.5	0.20	0.20	-	13.
^{232}Th	33.2	**0.21**	0.058	-	**26.8**
^{234}U	33.2	**0.100**	0.10	-	19.
^{235}U	1.7	-	0.009	-	**0.75**
^{238}U	30.8	**0.101**	0.088	-	**17.4**
^{237}Np	-	-	-	-	-
^{238}Pu	**0.013**	**0.017**	**0.055**	-	**0.26**
$^{239+240}Pu$	**0.508**	**1.1**	**2.06**	-	**4.00**
^{241}Am	**0.150**	-	**0.15**	-	**1.1**
$^{243+244}Cm$	-	0.11	-	-	-

Appendix A2: Radionuclides and Massic Activities in the Natural Matrix radioactivity SRMs (see IRD Procedure 16)

SRM Number	4355	4356	4357	4358	4359
Description	Peruvian Soil	Ashed Bone	Ocean Sediment	Ocean Shellfish	Seaweed
Radionuclide	Massic Activity ($mBq \cdot g^{-1}$) **Certified values are in bold type**.				
^{40}K	585.	49.	**225.**	In preparation	In preparation
^{55}Fe	2.	-	-	-	-
^{60}Co	<0.016	-	-	-	-
^{90}Sr	0.22	**42.6**	**4.4**	-	-
^{129}I	-	-	0.009	-	-
^{137}Cs	**0.33**	-	**12.7**	-	-
^{152}Eu	<0.23	-	-	-	-
^{154}Eu	<0.2	-	-	-	-
^{155}Eu	<0.2	-	1.4	-	-
^{208}Tl	12.,15.	-	-	-	-
^{210}Po	-	13.	14.	-	-
^{210}Pb	-	20.	24.	-	-
^{212}Pb	-	-	14.1		-
^{214}Bi	42.,39.	-	15.	-	-
^{226}Ra	-	**14.5**	**12.7**	-	-
^{228}Ra	-	6.1	**13.3**	-	-
^{228}Ac	-	6.9	-	-	-
^{228}Th	**42.2**	7.1	**12.1**	-	-
^{230}Th	**39.7**	**0.52**	**12.0**	-	-
^{232}Th	**43.0**	**0.98**	**13.0**	-	-
^{234}U	-	**0.64**	12.	-	-
^{235}U	-	0.028	0.6	-	-
^{238}U	-	**0.63**	12.	-	-
^{237}Np	-	-	0.007	-	-
^{238}Pu	3.,3.27	**0.86**	**2.29**	-	-
$^{239+240}Pu$	**0.0076**	**1.26**	**10.4**	-	-
^{241}Am	**0.004**	9.98	10.	-	-
$^{243+244}Cm$	-	**0.12**	-	-	-

Appendix A3.

National Institute of Standards & Technology

Certificate

Standard Reference Material 4404L, Lot 27
Thallium-201 Radioactivity Standard

This Standard Reference Material (SRM) consists of radioactive thallium-201 nitrate, non-radioactive thallium nitrate, and nitric acid dissolved in 5 mL of distilled water. The solution is contained in a flame-sealed NIST borosilicate-glass ampoule. The SRM is intended for the calibration of ionization chambers and solid-state gamma-ray spectrometry systems.

Radiological Hazard: The SRM ampoule contains thallium-201 with a total activity of approximately 30 MBq. Thallium-201 decays by electron capture. During the decay process, X-rays and gamma rays with energies from approximately 2 keV to 167 keV are emitted. Most of these photons escape from the SRM ampoule and can represent a radiation hazard. Approximate unshielded dose rates at several distances (as of the reference time) are given in note [a]*. Appropriate shielding and/or distance should be used to minimize personnel exposure. The SRM should be used only by persons qualified to handle radioactive material.

Chemical Hazard: The SRM ampoule contains nitric acid with a concentration of approximately 1 mole per liter of water. The solution is corrosive and represents a health hazard if it comes in contact with eyes or skin. If the ampoule is to be opened to transfer the solution, the recommended procedure is given on page 2. The ampoule should be opened only by persons qualified to handle both radioactive material and strong acid solution.

Storage and Handling: The SRM should be stored and used at a temperature between 5 and 65 °C. The solution in an unopened ampoule should remain stable and homogeneous until at least June 2005. The ampoule (or any subsequent container) should always be clearly marked as containing radioactive material. If the ampoule is transported it should be packed, marked, labeled, and shipped in accordance with the applicable national, international, and carrier regulations. The solution in the ampoule is a dangerous good (hazardous material) because of the radioactivity.

Preparation: This Standard Reference Material was prepared in the Physics Laboratory, Ionizing Radiation Division, Radioactivity Group, M.P. Unterweger, Acting Group Leader. The overall technical direction and physical measurements leading to certification were provided by D.B. Golas and O.T. Palabrica, Nuclear Energy Institute Research Associates. The support aspects involved in the preparation, certification, and issuance of this SRM were coordinated through the Standard Reference Materials Program.

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August 2004

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SRM 4404L, Lot 27, page 1 of 7

*Notes and references are on pages 5 to 7

Recommended Procedure for Opening the SRM Ampoule

1) If the SRM solution is to be diluted, it is recommended that the diluting solution have a composition comparable to that of the SRM solution.

2) Wear eye protection, gloves, and protective clothing and work over a tray with absorbent paper in it. Work in a fume hood. In addition to the radioactive material, the solution contains strong base and is corrosive.

3) Shake the ampoule to wet all of the inside surface of the ampoule. Return the ampoule to the upright position.

4) Check that all of the liquid has drained out of the neck of the ampoule. If necessary, gently tap the neck to speed the process.

5) Holding the ampoule upright, score the narrowest part of the neck with a scribe or diamond pencil.

6) Lightly wet the scored line. This reduces the crack propagation velocity and makes for a cleaner break.

7) Hold the ampoule upright with a paper towel, a wiper, or a support jig. Position the scored line away from you. Using a paper towel or wiper to avoid contamination, snap off the top of the ampoule by pressing the narrowest part of the neck away from you while pulling the tip of the ampoule towards you.

8) Transfer the solution from the ampoule using a pycnometer or a pipet with dispenser handle. NEVER PIPETTE BY MOUTH.

9) Seal any unused SRM solution in a flame-sealed glass ampoule, if possible, to minimize the evaporation loss.

See also reference [4]*.

*Notes and references are on pages 5 to 7.

PROPERTIES OF SRM 4404L, Lot 27, Ampoule 4

Certified values

Radionuclide	**Thallium-201**
Reference time	**1000 EST, 09 June 2004**
Massic activity of the solution [b]*	**5.858 MBq·g^{-1}**
Relative expanded uncertainty (k=2)	**0.80%** [c] [d]
Solution mass	**(5.2102 ± 0.0003) g** [e]
Solution density	**(1.040 ± 0.002) g·mL^{-1} at 20 °C** [e]

Uncertified values

Physical Properties:			
Source description	Liquid in flame-sealed NIST borosilicate-glass ampoule		
Ampoule specifications	Body outside diameter Wall thickness Barium content Lead-oxide content Other heavy elements	(16.5 ± 0.5) mm (0.60 ± 0.04) mm Less than 2.5% Less than 0.02% Trace quantities	
Chemical Properties:			
Solution composition	Chemical Formula	Concentration (mol·L^{-1})	Mass Fraction (g·g^{-1})
	H_2O HNO_3 $TlNO_3$ $^{203}TlNO_3$	53 1.2 4×10^{-4} 4×10^{-6}	0.93 0.07 1×10^{-4} 1×10^{-6}
Radiological Properties:			
Photon-emitting impurities	Tl-200: (9.3 ± 2.6) kBq·g^{-1} [e] [f] Tl-202: (9.5 ± 2.7) kBq·g^{-1} [e] [f]		
Half lives used	Thallium-200: (26.1 ± 0.1) h [g] [5] Thallium-201: (3.0423 ± 0.0014) d [g] [s] Thallium-202: (12.23 ± 0.02) d [g] [5] Radium-226: (1600 ± 7) a [g] [5]		
Calibration method and measuring instrument(s)	Pressurized "4π"γ ionization chamber A calibrated using a thallium-201 solution whose activity was determined by the 4π(e+X)-γ-coincidence efficiency-extrapolation technique.		

*Notes and references are on pages 5 to 7.

EVALUATION OF THE UNCERTAINTY OF THE MASSIC ACTIVITY [c] [d]*

Input Quantity x_i, the source of uncertainty (and individual uncertainty components where appropriate)	Method Used To Evaluate $u(x_i)$, the standard uncertainty of x_i (A) denotes evaluation by statistical methods (B) denotes evaluation by other methods	Relative Uncertainty Of Input Quantity, $u(x_i)/x_i$, (%) [h]	Relative Sensitivity Factor, $\lvert\partial y/\partial x_i\rvert \cdot (x_i/y)$ [i]	Relative Uncertainty Of Output Quantity, $u_r(y)/y$, (%) [j]
PIC A net response per gram of SRM 4404L, measured relative to RRS200 [k]	Standard deviation of the mean for >100 repeated measurements (A)	0.02	1.0	0.02
PIC A net response per Bq of thallium-201 in solution, measured relative to RRS200.	Standard deviation of the mean for >100 repeated measurements (A)	0.01	1.0	0.01
Activity used to calibrate PIC A net response per Bq of thallium-201 in solution	Standard uncertainty of the activity determined by the $4\pi(e+X)$-γ-coincidence efficiency-extrapolation technique. (B)	0.35	1.0	0.35
Half life of thallium-201 Half life of radium-226	Standard uncertainty of the half life (A)	0.04 [m] 0.44 [m]	0.02 [n] 0.012 [n]	0.001 0.005
Gravimetric measurements	Estimated (B)	0.05	1.0	0.05
Live time [p]	Estimated (B)	0.05	1.0	0.05
PIC A charge collection	Estimated (B)	0.05	1.0	0.05
Source positioning	Estimated (B)	0.05	1.0	0.05
Photon-emitting impurities	Estimated (B) [q] Estimated (B) [q] Limit of detection (B) [r]	14. 14. 100.	0.009 0.004 0.0004	0.13 0.06 0.04
Relative Combined Standard Uncertainty of the Output Quantity, $u_r(y)/y$, (%)				0.40
Coverage Factor, k				x 2
Relative Expanded Uncertainty of the Output Quantity, U/y, (%)				0.80

*Notes and references are on pages 5 to 7.

NOTES

[a] The Sievert is the SI unit for dose equivalent. See reference [1]. One μSv is equal to 0.1 mrem.

Distance from Ampoule (cm):	1	30	100
Approximate Dose Rate (μSv/h):	600	6	<1

[b] **Massic activity** is the preferred name for the quantity activity divided by the total mass of the sample. See reference [1].

[c] The reported value, y, of massic activity (activity per unit mass) at the reference time was not measured directly but was derived from measurements and calculations of other quantities. This can be expressed as $y = f(x_1, x_2, x_3, \ldots x_n)$, where f is a mathematical function derived from the assumed model of the measurement process. The value, x_i, used for each input quantity i has a **standard uncertainty**, $u(x_i)$, that generates a corresponding uncertainty in y, $u_i(y) = |\partial y/\partial x_i| \cdot u(x_i)$, called a **component of combined standard uncertainty** of y. The **combined standard uncertainty** of y, $u_c(y)$, is the positive square root of the sum of the squares of the components of combined standard uncertainty. The combined standard uncertainty is multiplied by a **coverage factor** of $k = 2$ to obtain U, the **expanded uncertainty** of y.

Since it can be assumed that the possible estimated values of the massic activity are approximately normally distributed with approximate standard deviation $u_c(y)$, the unknown value of the massic activity is believed to lie in the interval $y \pm U$ with a level of confidence of approximately 95 percent.

For further information on the expression of uncertainties, see references [2] and [3].

[d] The value of each component of combined standard uncertainty, and hence the value of the expanded uncertainty itself, is a best estimate based upon all available information, but is only approximately known. That is to say, the "uncertainty of the uncertainty" is large and not well known. This is true for uncertainties evaluated by statistical methods (e.g., the relative standard deviation of the standard deviation of the mean for the massic response is approximately 50%) and for uncertainties evaluated by other methods (which could easily be over estimated or under estimated by substantial amounts). The unknown value of the expanded uncertainty is believed to lie in the interval $U/2$ to $2U$ (i.e., within a factor of 2 of the estimated value).

[e] The stated uncertainty is two times the standard uncertainty.

[f] Estimated limits of detection for photon-emitting impurities, as of the reference time, expressed as massic photon emission rates, are:
1×10^2 s^{-1}·g^{-1} for energies between 30 keV and 40 keV,
3×10^2 s^{-1}·g^{-1} for energies between 40 keV and 163 keV,
1×10^2 s^{-1}·g^{-1} for energies between 171 keV and 240 keV,
4×10^1 s^{-1}·g^{-1} for energies between 240 keV and 1450 keV, and
2×10^1 s^{-1}·g^{-1} for energies between 1450 keV and 3600 keV, provided that the photons are separated in energy by 4 keV or more from photons emitted in the decay of thallium-201.

[g] The stated uncertainty is the standard uncertainty.

[h] Relative standard uncertainty of the input quantity x_i.

[i] The relative change in the output quantity y divided by the relative change in the input quantity x_i. If $|\partial y/\partial x_i| \cdot (x_i/y) = 1.0$, then a 1% change in x_i results in a 1% change in y. If $|\partial y/\partial x_i| \cdot (x_i/y) = 0.05$, then a 1% change in x_i results in a 0.05% change in y.

[j] Relative component of combined standard uncertainty of output quantity y, rounded to two significant figures or less. The relative component of combined standard uncertainty of y is given by $u_i(y)/y = |\partial y/\partial x_i| \cdot u(x_i)/y = |\partial y/\partial x_i| \cdot (x_i/y) \cdot u(x_i)/x_i$. The numerical values of $u(x_i)/x_i$, $|\partial y/\partial x_i| \cdot (x_i/y)$, and $u_i(y)/y$, all dimensionless quantities, are listed in columns 3, 4, and 5, respectively. Thus, the value in column 5 is equal to the value in column 4 multiplied by the value in column 3. The input quantities are independent, or very nearly so. Hence the covariances are zero or negligible.

[k] The response of pressurized ionization chamber A (PIC A) is determined from measurement of the time required to collect a given amount of charge on a stable fixed capacitor. All of the response measurements in the NIST pressurized ionization chambers are made relative to the response of one or more artifact standards. These artifact standards consist of microgram quantities of aged radium-226 in small welded stainless-steel capsules. These capsules are encapsulated in plastic rods whose dimensions are similar to those of the standard NIST ampoule. The artifact standards are called **Radium Reference Sources** and are designated as RRSx, where x is the nominal mass (in micrograms) of radium-226 in the capsule.

[m] The relative standard uncertainty of $\lambda \cdot t$ is determined by the relative standard uncertainty of λ (i.e., of the half life). The relative standard uncertainty of t is negligible.

[n] $|\partial y/\partial x_i| \cdot (x_i/y) = |\lambda \cdot t|$

[p] The live time is determined by counting the pulses from a gated crystal-controlled oscillator.

[q] The standard uncertainties given are for the detected impurities. $|\partial y/\partial x_i| \cdot (x_i/y) = \{$(response per Bq of impurity)/(response per Bq of Tl-201)$\} \cdot \{$(Bq of impurity)/(Bq of Tl-201)$\}$.

[r] The standard uncertainty for each undetected impurity that might reasonably be expected to be present is estimated to be equal to the estimated limit of detection for that impurity, i.e. $u(x_i)/x_i = 100\%$. $|\partial y/\partial x_i| \cdot (x_i/y) = \{$(response per Bq of impurity)/(response per Bq of Tl-201)$\} \cdot \{$(Bq of impurity)/(Bq of Tl-201)$\}$. Thus $u_i(y)/y$ is the relative change in y if the impurity were present with a massic activity equal to the estimated limit of detection.

[s] This is the equally-weighted mean and the standard deviation of the mean of five published half-life values for thallium-201:

	Published Half Life and One Standard Uncertainty	Standard Deviations From the Mean
1.	(3.0456 ± 0.0015) days [6]	+1.1
2.	(3.043 ± 0.003) days [7]	+0.3
3.	(3.0408 ± 0.0013) days [8]	-0.5
4.	(3.0379 ± 0.0007) days [9]	-1.5
5.	(3.0440 ± 0.0048) days [9]	+0.6

Mean (3.0423 ± 0.0014) days = (73.015 ± 0.015) hours

The value currently recommended in the Evaluated Nuclear Structure Data File (ENSDF) is based upon only value number 4 above. We believe that all of the above data should be considered and that a larger uncertainty is appropriate.

REFERENCES

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[3] B. N. Taylor and C. E. Kuyatt, *Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results*, NIST Technical Note 1297, 1994. Available from the Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20407, U.S.A.

[4] National Council on Radiation Protection and Measurements Report No. 58, *A Handbook of Radioactivity Measurements Procedures*, Second Edition, 1985. Available from the National Council on Radiation Protection and Measurements, 7910 Woodmont Avenue, Bethesda, MD 20814 U.S.A.

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